Sewage Works Journal

Published by

Federation of Sewage Works Associations

Lancaster, Pa.

Copyright, 1937, by Federation of Sewage Works Associations

Vol. IX May, 1937 No. 3

Sewage Research:

Studies in the Digestion of Ground Garbage. By W. L. Malcolm 389

Chemical Coagulation of Sewage VII. Effect of Garbage. By Willem Rudolfs and Robert S. Ingols 406

The "Slope" Method of Evaluating the Constants of the First-Stage B.O.D. Curve. By Harold A. Thomas, Jr. 425

II. Factors Influencing the Clarification of Sewage by Activated Sludge. By H. Heukelekian 431

Plant Operation:

North Outfall Sewer Inspection, City of Los Angeles. By Reuben F. Brown 446

Symposium on Mechanical Equipment 455

Pumps, Bearings, Clarifiers and Plant Layout. By Carl F. Tennant.
Screens and Roll Presses. By J. H. Van Norman.
Ferric Chloride Feeders and Comminutors. By Alfred W. Wyman.
Automatic Control of Skimmers, Sludge Pumps, Gas Engines and Waste Gas. By H. M. Ely.

Mechanical Filtration of Effluents. By S. I. Zack 466

Trickling Filter Operation Results at Worcester, Mass. By Roy S. Lanphear 476

Harbor Pollution:

Wastes Disposal as Related to Shellfish. By Arthur P. Miller 482

Progress in Controlling Pollution of Rhode Island Waters. By Walter D. Shea.... 493

Industrial Wastes:

Industrial Wastes and Their Effects on Municipal Sewage Treatment Plants. By L. F. Oeming 503

Operators' Reports and Suggestions:

Standard Methods of Sewage Analysis. By W. D. Hatfield 510

Trickling Filters. By W. H. Wisely 513

Editorial:

The Anniversary Volume 516

The Passing of Friends and Colleagues 517

Reviews and Abstracts:

The Biologic Digestion of Garbage with Sewage Sludge. By H. E. Babbitt, B. J. Leland and F. H. Whitley, Jr. 518

Chemical Methods of Treating Sewage. British, American and German Practice: A Symposium and Discussion 522

Partial Treatment of Sewage by the Activated Sludge Process. By F. E. Pipe and J. E. Farmer 524

Dispersed and Colloidal Matter in Sewage. By E. V. Mills 525

Sewage Disposal Abroad. By J. M. Antill 528

Processes in the Digestion Chamber of Imhoff Tanks. By Dr.-Ing. Husmann 528

The Effect of Iron and Aluminum Salts on the Activated Sludge Process. By Dr.-Ing. Nesmehanoff 529
The Sewage from the Tannery City Backnang. By Architect Wimmer 529
Experiments on Purification of Packing-House Wastes at Mason City, Iowa. By Max Levine, F. G. Nelson and Elmer Dye 530
Beet Sugar Factory Waste Treatment. By E. F. Eldridge 531
Spray Drying of Steffens Waste. By E. F. Eldridge and F. R. Theroux 533
The Design and Operating Results of a Typical Milk Waste Filter. By E. F. Eldridge 534
The Economic Importance of Waste Treatment to the Industries. By Michael J. Blew 535
Some Ecologic Factors Affecting the Distribution of the Protozoa. By James B. Lackey 537
A Quantitative Study of the Elbe River with Particular Consideration of the Influence of Sewage on the Process of Biological Self-Purification. By Theodore Seeler 539
Venturi Flumes for Sewers. By H. K. Palmer 540
Sewage Disposal for the Nation's Capital. By Frank A. Marston 541
Sewage Treatment for Denver. Anonymous 542
Public Water Pollution Control in New Hampshire. By C. D. Howard 542
References to Sewage Literature 543

JOIN YOUR STATE OR LOCAL SEWAGE WORKS ASSOCIATION

AFFILIATE WITH THE NATIONAL FEDERATION OF SEWAGE WORKS ASSOCIATIONS

Members of the Federation receive

THE SEWAGE WORKS JOURNAL

for one dollar per year

Non-members' subscription fee $3.00 per year, which includes subscription at $2.00 and service information fee of $1.00; Canada, $3.50; other countries, $4.00.

Send Subscriptions to

WM. W. BUFFUM, Business Manager
654 Madison Ave.
New York, N. Y.

Sewage Research

STUDIES IN THE DIGESTION OF GROUND GARBAGE *

CORNELL UNIVERSITY, 1936

By W. L. Malcolm

Professor of Municipal Engineering, Queen's University, Kingston, Ontario

In the course of an inspection of a number of sewage disposal plants of the United States and Canada in the early part of 1935, it was suggested to the author, by engineers at Columbus, Baltimore, and the Engineering Experiment Station of the University of Illinois, that sewage treatment plants might be required to handle a heavy additional organic load of macerated or ground garbage. It was further noted that certain commercial firms were placing on the market garbage grinders for domestic use.

The author later discussed this problem with the members of the Sanitary Engineering Department at Cornell University, with the result that he was authorized by the School of Civil Engineering to proceed with an investigation of the digestion of sludge and garbage.

The Problem

The problem was to ascertain if ground garbage alone, or combinations of ground garbage and raw sludge, would digest if the digestion units were seeded with well-digested sludge.

Equipment and Method

Oil drums of 55 gal. capacity each were remodelled for use as digesters. Each drum was very carefully cleaned and thoroughly washed, then seeded with from 30 to 35 gallons of well digested sludge obtained from the digestion tank of the Ithaca Sewage Treatment Plant.

1935 Experimental Work

The work in 1935 was carried out at the site of the Sewage Treatment Plant at Ithaca, N. Y., during the summer months.

The site chosen was under the coverage provided by the frame building, about 8 ft. to 10 ft. high, over the old septic tanks. The units were boxed in, in the hope that they could be kept at a constant temperature. However, the heating units provided were insufficient and the feeding of the sludge and garbage became almost impossible because of cold weather in the later period. The heat during the summer weather was too severe, often going over 100° F. A great drawback was the dis-

* Presented Before the Ninth Annual Meeting of the New York State Sewage Works Association, New York City, Jan. 22, 1937.

tance of the plant from the laboratory, which made the handling of samples arduous and lengthy.

For two months in 1935 the work was carried out by the author and then continued by certain graduate students during October and November. The results, though covering only a short period, justified the author's suggestion that the work be continued in 1936 for a considerably longer period.

1936 Experiments

Early in 1936 it was suggested that the plant be moved to the University, as near to the Sanitary Laboratory as possible. This was finally arranged by taking over a large basement room in one of the buildings about 100 yards from the Sanitary Laboratory. This room had an outside entrance. Heat, electricity and water were provided.

The digesters were set on a low rack, with the gas collection drums behind and somewhat above the digesters.

Views of this plant are shown in Figs. 1 and 2.

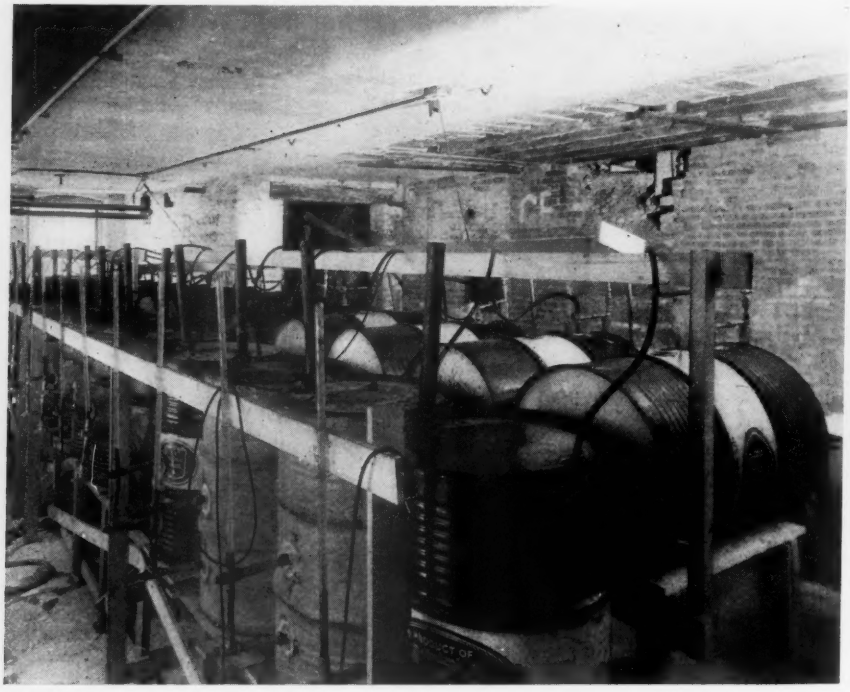


Fig. 1.—55-gallon experimental digestion tanks.

The Materials Used in the Experiment

Digested Sludge.—Sludge for seeding was obtained, as noted, from the Ithaca digestion tank. From 30 to 35 gallons were placed in each digester on April 14, 1936.

Raw Sludge.—Ten gallons of raw sludge from the Ithaca plant were brought up daily for six days of each week by truck. Garbage was obtained at the Students' Union, Willard Straight, each week day.

Garbage.—The garbage consisted of the scrapings from the tables, usually of the noon meal. It was composed of meats, vegetables, both cooked and uncooked, corn cobs, fruit skins, bread and similar things left on the diners' plates. No raw vegetable tops or cuttings were used, owing to the difficulty of obtaining them at the Union.

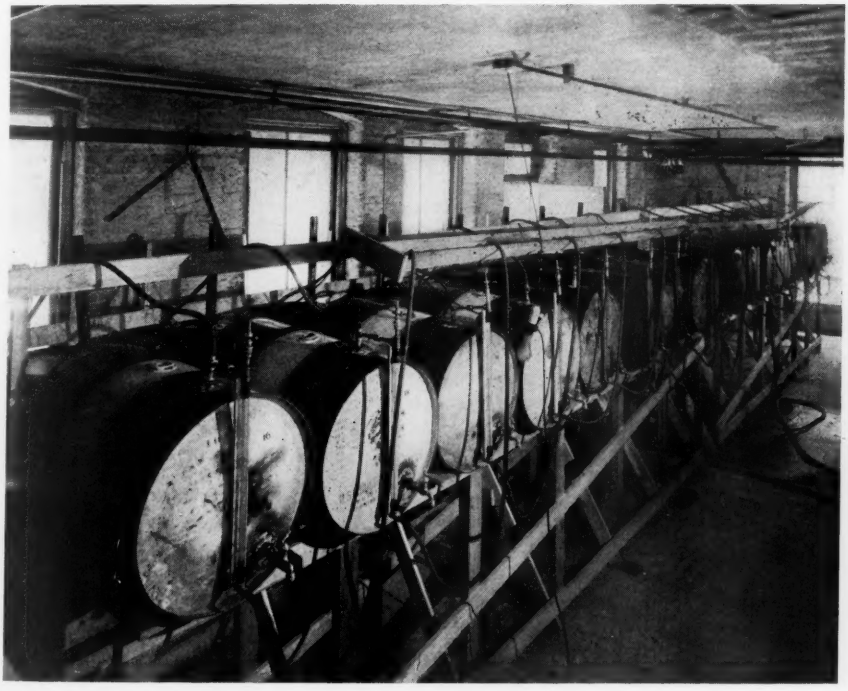


FIG. 2.—Gas collecting tanks.

PREPARATION OF THE GARBAGE

In 1935 the garbage was ground by hand with an ordinary kitchen grinder. In 1936, by courtesy of the General Electric Company, a "Handy Kitchen Unit" was provided whereby the garbage was ground by electric power, the unit being placed under a sink. A valve was provided at the bottom of the trap under the grinder to obtain the garbage as ground. The operation was performed with as little water as possible. The grinder was thoroughly washed out after each grinding by simply running cold water through it (the method suggested by the manufacturers).

A Detailed Description of the Plant

As it was necessary at any time to add or take materials from the tanks, to determine the gases and to note sludge levels, methods had to be provided for

(*a*) Feeding the tanks
(*b*) Collecting and measuring the gas
(*c*) Withdrawing the sludge
(*d*) Noting the height of the contents of the tank at any time.

The digestion units were set on end. To permit the additions to be charged, 2 in. diameter pipes were provided at the top, of sufficient height so that back pressure would not cause them to overflow. For withdrawals a 2 in. pipe and valve were provided at the bottom, through which sludge could be drawn off at any time. To provide for gas collection a ½ in. opening at the top was connected to the gas-collecting-unit by means of ⅜ in. rubber tubing. Two ¾ in. bushings were brazed to the side of the drum and connected by nipples to a ½ in. gauge glass. This gauge glass had to be of sufficient height to prevent overflow by back pressure. These units were set on racks so that the bottom of the draw-off pipe was just sufficiently clear of the floor to permit a pail for collecting the sludge to be placed below it.

The gas collectors were also 55 gallon oil drums, since funds did not permit the purchase of meters. The collectors were provided with a connecting nipple brazed to the top of the drum, for the gas tubing from the digesters. A glass gauge was provided at one end, to note the height of the contents. A rubber tube of ⅜ in. diameter was connected from the lower part of the drum (actually to the lower end of the gauge connection) to an overhead trough, to provide an exit for the water displaced by the gas. A ½ in. tap with hose connection was brazed to the lower part of the drum. This provided a method of refilling by connecting to a water line, and also a method of running water out of the tanks to balance the pressure inside and outside the drum when the quantity of gas was read. When gas was to be removed from the tanks, the water line was connected up, and the gas blown into the open air outside the building through the gas tap at the upper end of the gauge glass. The tanks were first filled with water, which was withdrawn ½ cu. ft. at a time. The gauge glass was carefully calibrated or marked for each half foot of withdrawal. In Fig. 3 the line drawings show these details.

Digestion

It was decided that the measurement of digestion would be made in two ways—

(*a*) By a determination of the amounts of volatile matter remaining in the sludges as drawn from the digestion units.

(*b*) By a determination of the amount of gas produced and its quantitative relation to the weight of volatile matter added.

The Additions or Charges to the Tanks

Since raw sludge was obtainable only at the Ithaca Plant, it was decided to operate these digestion units in the same manner as the operation of the digestion tank of the Ithaca plant. The raw sludge

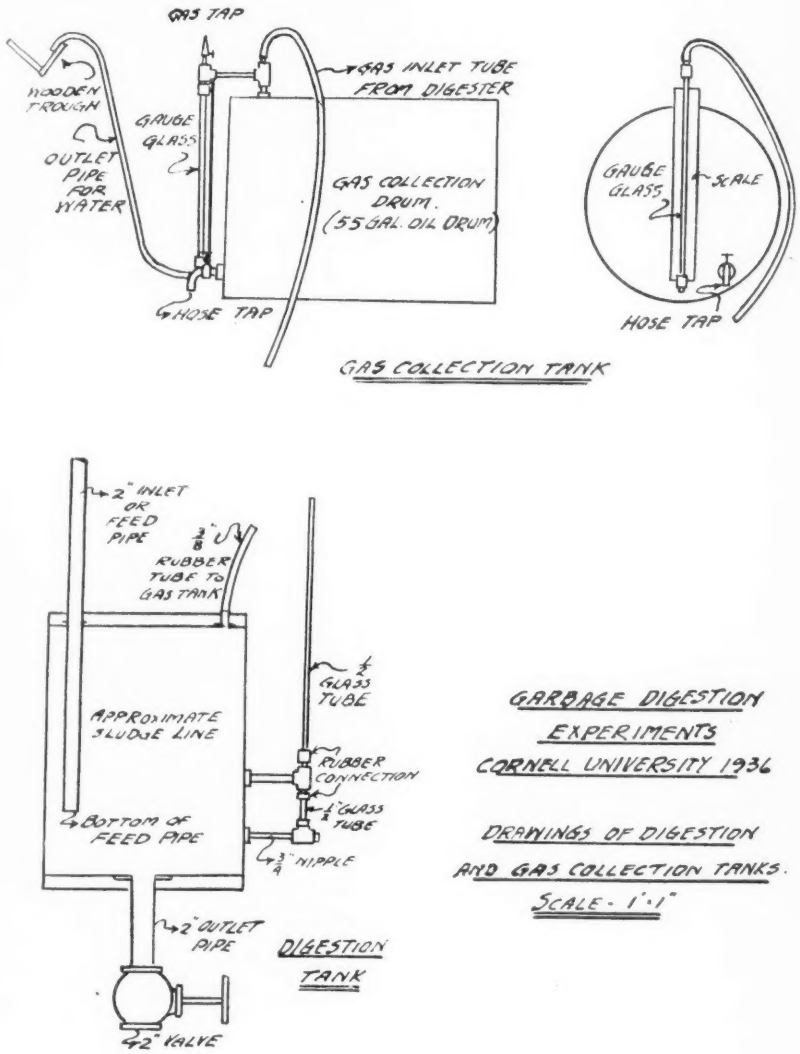


Fig. 3.

was obtained, during the pumping of the sludge from the city sedimentation units to the digester, by means of a ¾ in. pipe let into the main sludge pipe.

The Ithaca plant produces some 7000 gallons of raw sludge daily, which is pumped to a digestion tank of 264,375 gallons capacity. This makes the daily charge 2.65 per cent. In June, 1935, the available information indicated that this sludge contained 4½ per cent solids, of which 70 per cent was volatile; the sp. gr. was 1.02.

Digested solids from the city digestion tank contained 8 per cent total solids and 60 per cent volatile, with sp. gr. of 1.04. This information was obtained from Mr. Huff, a graduate student.

The initial charge for each drum was considered as 30 gallons. Therefore the volume of raw sludge to be added to the tanks daily was $30 \times .0265 = 0.8$ gal. Volatile content of this sludge was .214 lb. In 30 gallons of digested sludge the total volatile solids were 12.5 lb. Thus the relation of the volatile solids in the raw sludge to the volatile solids in the digested was 1.71 per cent.

The garbage was first assumed to be produced at the rate of ½ lb. per capita per day, containing 90 per cent volatile matter and 25 per cent solids. The total amount for Ithaca would then be 12,000 lb. daily. This would give 1.72 lb. of garbage to 1 gal. of sludge. Volatile matter in the garbage would be .387 lb.

$$\text{Thus}\frac{\text{The volatile matter in sludge}}{\text{The volatile matter in garbage}} = \frac{.269}{.387} = \frac{1}{1.5} \text{ approximately.}$$

This proportion of sludge to garbage was considered the probable or normal one. Additional experiments, however, were carried out with two other proportioned mixtures of garbage and sludge, with garbage additions alone, and with raw sludge additions alone. This latter was considered the "control." The other proportions of mixed garbage and sludge were set empirically at 1:2 and 1:1.

During 1935 and from April 22 to May 30, 1936, all the sludge was measured volumetrically, the garbage being weighed. After the latter date, the raw sludge additions were all by weight.

The details of the additions to tanks to May 30, 1936 (38th day), are given in Table I*A*.

TABLE I*A*

Tank Nos.	Daily Charge of Sludge, Gal.	Daily Charge of Garbage, Gm.	Ratio Based on Vol. Matters
2–3	nil	432 Gm.	
4–5	.80 gal. U. S.	nil	
7–8	.32	258	1 : 1½
9–10	.265	286	1 : 2
11–12	.40	216	1 : 1

No difficulty was found in adding the garbage mixed with sludge to tanks 7–8–9–10–11 and 12, but it was found advisable to add one quart of water to the garbage required for tanks 2 and 3, after it was weighed. This did not affect the quantities of volatile matter added.

TABLE I*B*

After May 30, 1936 (38th day), the quantities were changed to the following, the sludge being weighed instead of measured volumetrically:

Tank Nos.	Daily Charge of Sludge	Daily Charge of Garbage	Ratio of Vol. Matter in Sludge to Vol. Matter in Garbage
2–3	nil	432 Gm.	—
4–5	6.75 lb.	nil	—
7–8	2.75 lb.	258 Gm.	1 : 1½
9–10	2.25 lb.	286 Gm.	1 : 2
11–12	3.25 lb.	216 Gm.	1 : 1

THE TEMPERATURE

The room was heated in the early stages by steam and then later by the use of electrical heaters of the office type. At no time was the temperature at the optimum for digestion, *i.e.*, about 84° F. (or 29° C.) but as all the drums were at the same temperatures at any time, the results were at least of comparative value.

The average temperature was 19.8° C., or about 67° F.

The raw sludge and garbage actually added to the tanks, had the following characteristics—

TABLE II

	Moisture	Volatile Matter	Vol. to Total	pH
	Per Ct.	Per Ct.	Per Ct.	
Raw sludge				
Average	96.3	74.4	2.73	5.64
Max.	98.6	88.0	6.36	6.40
Min.	91.7	61.7	0.98	5.20
Garbage				
Average	83.8	94.7	14.41	4.71
Max.	97.8	99.5	24.95	6.0
Min.	73.8	83.5	2.02	3.6

The details, as taken day by day, are shown on Figs. 4 and 5.

The average proportions of garbage and sludge were—

Tanks 7 and 8—average .0705 lb. volatile of garbage and .0626 lb. volatile of sludge per day which is a ratio of *1.25 to 1½* instead of *1 : 1½*.

Tanks 9 and 10—average .076 lb. volatile of garbage and .0514 lb. volatile of sludge per day which is a ratio of *1.348 : 2* instead of *1 : 2*.

Tanks 11 and 12—average .0581 lb. volatile of garbage and .0736 lb. volatile of sludge daily which is a ratio of *1.268 : 1* instead of *1 : 1*.

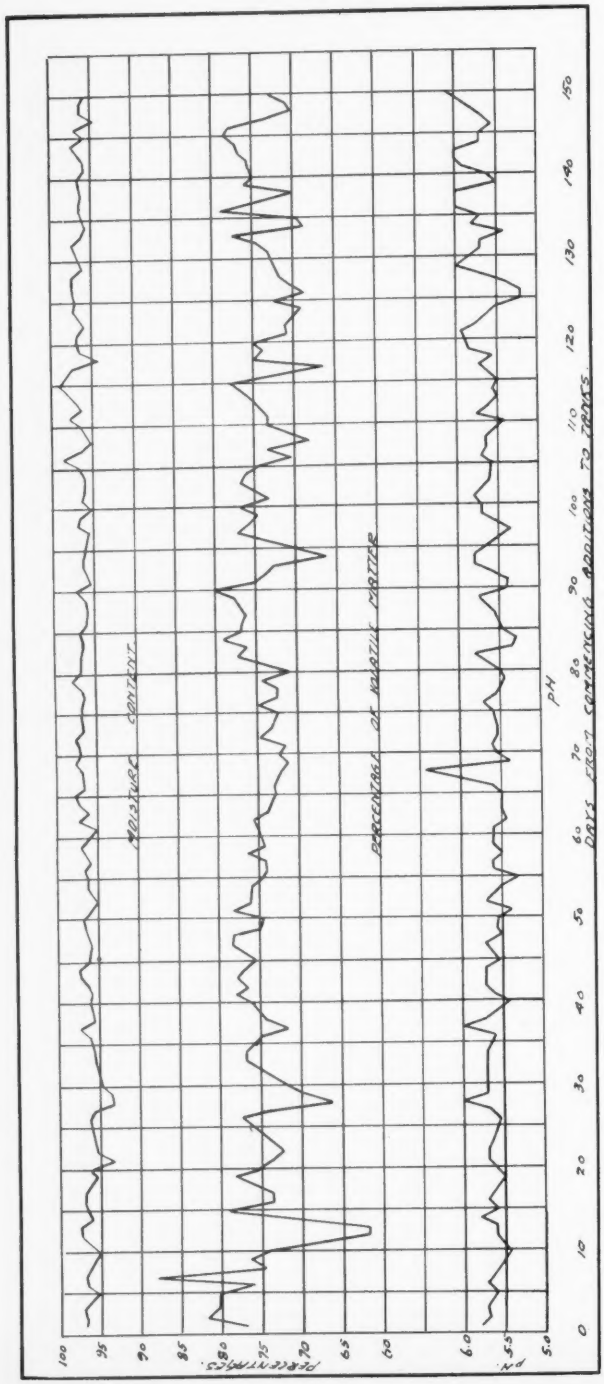


FIG 4.—Garbage digestion experiments, Cornell University, 1936. Raw sludge. Moisture content, volatile matter, pH.

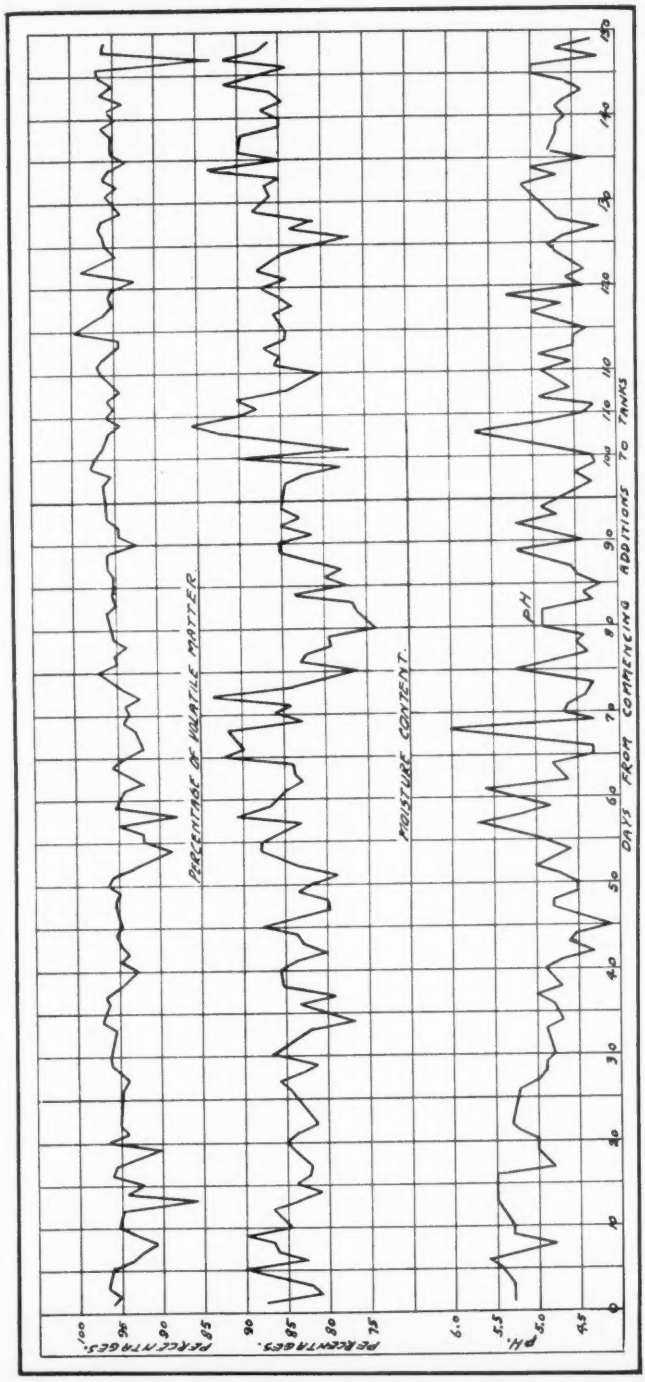


FIG. 5.—Garbage digestion experiments, Cornell University, 1936. Garbage. Moisture content, volatile matter, pH.

The total volatiles as added to the tanks were, when averaged—

Tanks 4 and 5—control—sludge only,		.1537 lb. daily.
2 and 3—garbage—garbage only,		.1158 lb. daily.
7 and 8—garbage and sludge "normal,"		.1331 lb. daily.
9 and 10—	do	.1274 lb. daily.
11 and 12—	do	.1317 lb. daily.

This is somewhat less than the amount computed on page 7, *i.e.*, .214 lb.

The analyses of the contents of the tanks were as follows—

TABLE III.—*Analyses of Sludges in Tanks*

	Before Additions		Last Withdrawal (150th day)	
	Moisture	Vol.	Moisture	Vol.
	Per Ct.	Per Ct.	Per Ct.	Per Ct.
Tanks 4–5	84.9	49.4	89.6	52.7
2–3	89.0	50.3	91.7	54.0
7–8	91.8	52.9	88.6	51.6
9–10	90.8	49.8	89.2	51.9
11–12	89.1	41.6	89.8	54.1

In each case the average of samples from each pair of tanks is given.

Figure 6 shows the analyses of the withdrawals in tanks 4 and 5 to indicate how the tanks in pairs conformed to the general trend and Fig. 7 shows the details of sludge withdrawals for all tanks.

The ratio of 0.8 gallons of sludge added, to an average capacity in each tank of 35 gallons, gives a digestion period of 44 days. This corresponds fairly closely with the period laid down by the Sludge Committee of the Sanitary Engineering Section of the A. S. C. E., for sludge digestion at an average temperature of 19.8° C. or 67.3° F.

Table III shows that in all cases a fairly uniform result was obtained in the digestion of all the varied sludges, the moisture averaging approximately 90 per cent and volatile content slightly above 50 per cent.

GAS PRODUCTION—QUANTITIES

The fairest method of comparing the gas production is on the basis of gas produced per pound of volatile solids added. The results of these calculations are shown in Table IV.

In the early days of the experiments, certain tanks apparently were not producing gas. Later, after a long and careful check, using soap solution, it was found that extremely small leaks in the brazing or in the plumbing were the cause of the trouble.

It was therefore necessary to compensate for these gas losses in making calculations. This was done by assuming that the gas generated in any digester would be equal to the gas in its "mate" provided the latter had been collecting gas. In case both gas collection

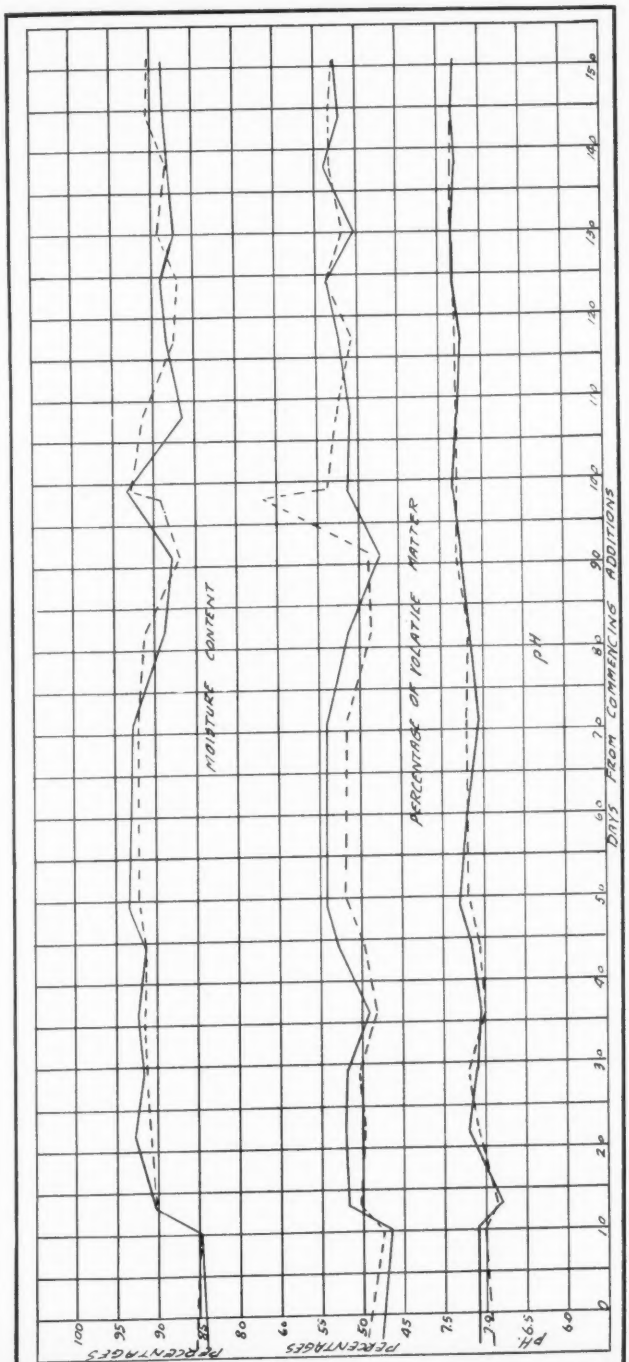


FIG. 6.—Garbage digestion experiments, Cornell University, 1936. Sludge withdrawals. Tanks 4 and 5, additions, raw sludge only. Moisture content, volatile matter, pH. Tank 4 ———; Tank 5 — — —.

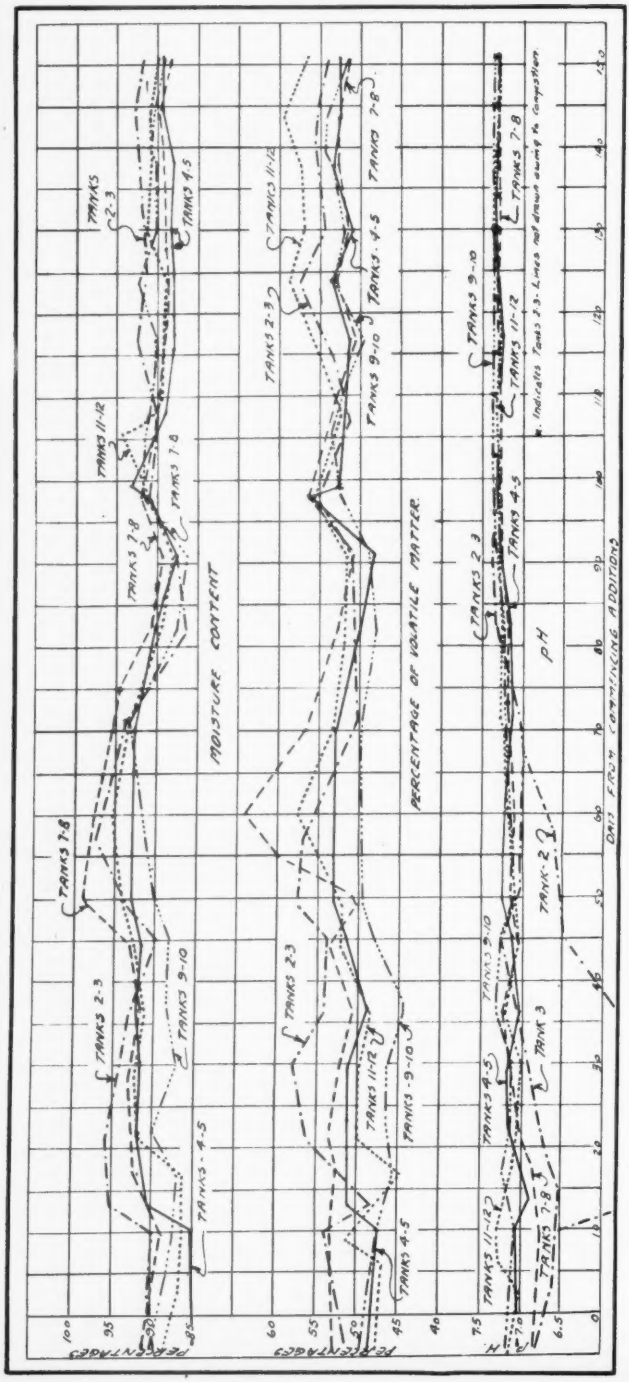


FIG. 7.—Garbage digestion experiments, Cornell University, 1936. Sludge withdrawals. Averages of pairs of tanks given. Tanks 2–3 —·—·—; Tanks 4–5 ———; Tanks 7–8 — — — —; Tanks 9–10 ——·——; Tanks 11–12 ·····.

TABLE IV.—*Cubic Feet of Gas Produced by Digesters*

Tank No.	Cu. Ft. Gas at 0° C. and 760 m.m.	No. of Days
2	208.35	151
3	213.94	151
4	252.51	153
5	239.63	153
7	211.65	151
8	212.94	151
9	195.34	151
10	193.27	151
11	199.58	151
12	203.81	151

drums were leaking, the adjustment was made by assuming that the gas produced in each of the pair would be equal to that of a tight unit containing the nearest equivalent combination of added materials. This will be noted in certain of the graphs pertaining to gas production, viz.—Figs. 8 and 9. Figure 8, showing the individual pairs, Tanks 4 and 5 and Tanks 9 and 10, shows how closely the tanks of any pair checked each other.

The gas produced in the various drums was reduced to 760 mm. of mercury pressure and 0° C., due allowance being made for vapor pressure. Table IV shows the total gas produced.

The quantity in cubic feet of gas produced per pound of volatile material added is shown in Table V.

TABLE V.—*Cubic Feet of Gas Produced per Lb. of Volatile Matter Added*

Tanks	
4–5—Sludge only	10.63
2–3—Garbage only	12.15
7–8—Mixture	10.70
9–10—Mixture	10.19
11–12—Mixture	10.21

This shows a fairly constant ratio.

Day by day cumulative quantities and ratios are shown in Fig. 9.

TABLE VI.—*Gas Characteristics.*

Percentage Contents of the Gases Generated

Tanks Nos.	CO_2	CH_4	H_2	O_2	Undet.
4–5	23.23	56.32	5.27	1.04	14.13
2–3	27.45	53.59	4.40	1.70	12.84
7–8	27.02	55.08	5.18	1.44	11.28
9–10	26.76	55.25	5.80	1.46	10.74
11–12	26.30	52.71	7.62	.66	12.72
Average	26.15	54.59	5.65	1.27	12.34

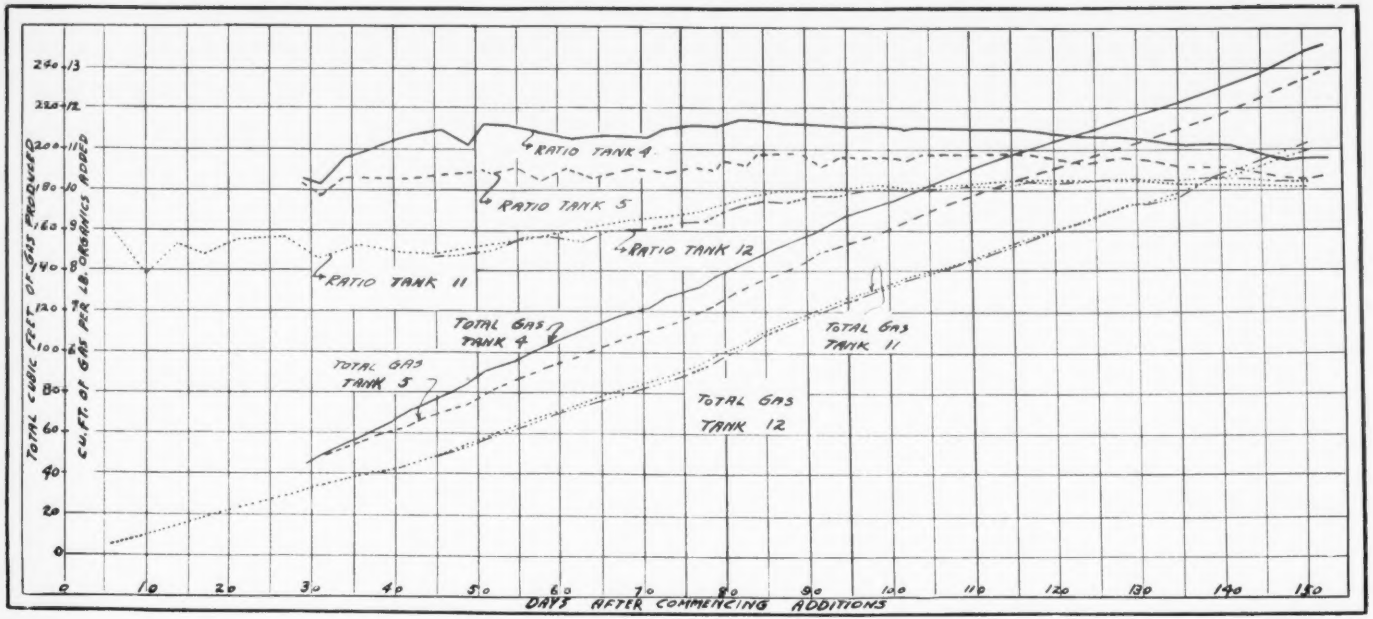

TOTAL CUBIC FEET OF GAS PRODUCED
CU. FT. OF GAS PER LB. ORGANICS ADDED
RATIO TANK 4
RATIO TANK 5
RATIO TANK 12
RATIO TANK 11
TOTAL GAS TANK 4
TOTAL GAS TANK 5
TOTAL GAS TANK 11
TOTAL GAS TANK 12
DAYS AFTER COMMENCING ADDITIONS

FIG. 8.—Garbage digestion experiments, Cornell University, 1936. Gas production. Total gas produced and cubic feet of gas per pound of added volatile matter. Tanks 4–5, control tanks, raw sludge only added; Tanks 11–12, garbage and raw sludge added; Tank 4 ———; Tank 5 — — —; Tank 11 ·····; Tank 12 —·—·—.

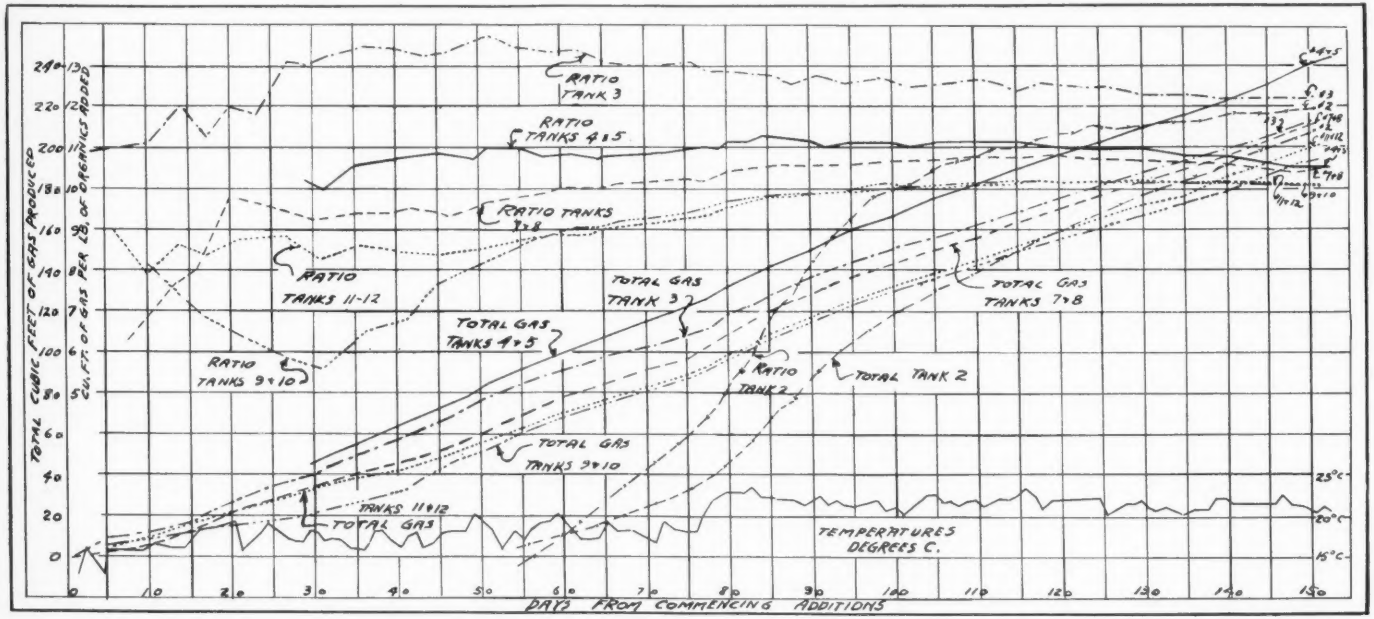

TOTAL CUBIC FEET OF GAS PRODUCED
CU. FT. OF GAS PER LB. OF DIGESTIBLES ADDED
RATIO TANK 3
RATIO TANKS 4 & 5
RATIO TANKS 7 & 8
RATIO TANKS 11-12
RATIO TANKS 9 & 10
TOTAL GAS TANK 3
TOTAL GAS TANKS 4 & 5
TOTAL GAS TANKS 7 & 8
RATIO TANK 2
TOTAL TANK 2
TOTAL GAS TANKS 9 & 10
TANKS 11 & 12
TOTAL GAS
TEMPERATURES DEGREES C.
25°C.
20°C.
15°C.
DAYS FROM COMMENCING ADDITIONS

FIG. 9.—Garbage digestion experiments, Cornell University, 1936. Gas production. Total gas produced and cubic feet of gas per pound of added volatile matter. Tank 2 ———; Tank 3 —·—·—; Tanks 4–5 ——— (average); Tanks 7–8 — — — (average); Tanks 9–10 —·····— (average); Tanks 11–12 ····· (average).

There are no definite characteristics displayed in these results that show any particular trend.

The CO_2, CH_4 and H_2 percentages, while varying considerably in all units from time to time, show a remarkably uniform average.

Conclusion

As measured by volatile solids determinations or by gas production, either quantitative or qualitative, there appears to be no difficulty in the digestion of macerated garbage, either alone or with raw sludge in any proportion, in tanks seeded with well digested Ithaca sludge.

Notes on Operation

At no time was there any foaming.

Keefer and Kratz report that the Baltimore garbage formed a mat or scum on the surface. At no time during the experiments at Ithaca was there any evidence of scum. Further, on dismantling the plant at the end of September, 1936, the author did not find any evidence that scum had formed. Possibly the method of adding the sludge and garbage near the bottom of the tank in some measure gave a very satisfactory distribution of all the solids, which were held throughout the sludge body rather than on the surface.

Solids Balance.—A check on the solids balance was made only on the volatile matter. The results are tabulated in Table VII.

Table VII.—*Volatile Solids Balance*

	Percentage of Volatiles Accounted For
Tanks 4–5	83.8
2–3	76.5
7–8	90.9
9–10	93.8
11–12	95.4

All tanks were operated with the same technique. No explanation can be offered by the author to account for the differences.

B.O.D.—In 1935, five-day B.O.D. determinations were made, but in 1936 no such work was done. The author inclines to the belief that this work has little value in sludge determinations. The sludge is not oxidized or turned into a watercourse to be oxidized by the dissolved oxygen therein. He believes that either the percentage of volatiles in the sludge or the gas produced—to the pounds of volatiles added are of infinitely more value as criteria of digestion than the B.O.D.

pH.—As may be observed in Fig. 7, there was a tendency for the pH of the digesters to lessen at first, but as the bacterial flora in the tanks became more adjusted to the feedings the pH increased. Finally all the tanks were well adjusted above 7.0, *i.e.*, on the alkaline side. Practically all pH's were taken on a capillary set (SDC). The

final pH's are shown in Table VIII and show practically the same alkalinity between 7.30 and 7.35.

TABLE VIII.—*pH of Tank Sludges—Final Sludge Withdrawals*

Tank	pH
4	7.30
5	7.30+
2	7.30
3	7.30+
7	7.30
8	7.35
9	7.35
10	7.30
11	7.30
12	7.30+

ACKNOWLEDGMENT

The work was done under the supervision of the Department of Sanitary Engineering, School of Civil Engineering, Cornell University. The author is greatly indebted to Professor H. M. Ogden for his helpful criticism, to Professor C. L. Walker for assistance in operation and interpretation of results, and to Dean S. C. Hollister for allocating funds for the work.

The cooperation of the officials of the city of Ithaca, namely Messrs. H. Eustance, the City Engineer, and J. Woodford the Superintendent of Sewers, was of great value and is very much appreciated. Finally, the daily routine of pumping the sewage sludge into the containers could only have been carried out with the kindly assistance of Mr. C. Kerr, Chief Operator, and his assistants.

REFERENCES

(The references are to articles prior to the commencement of these experiments, *i.e.*, prior to June, 1935.)

1. C. R. Fox and W. S. Davis, "New Method of Disposing of Garbage," *Eng. and Cont.*, **62**, 800, Oct. 8, 1924.
2. C. G. Hyde, "The Thermophilic Digestion of Municipal Garbage and Sewage Sludge, with Analogies," *This Journal*, **4**, 993, Nov., 1932.
3. G. M. Fair, "Digestion of Garbage," *This Journal*, **6**, 259, March, 1934.
4. C. E. Keefer, "Sewerage System Utilized for Disposal of Garbage," *Eng. News-Record*, **112**, 227–240, Feb. 15, 1934.
5. C. E. Keefer and H. Kratz, "The Digestion of Garbage with Sewage Sludge," *This Journal*, **6**, 14, 1934.
6. C. E. Keefer and H. Kratz, "The Quantity of Garbage that can be Digested with Sewage Sludge," *This Journal*, **6**, 250, March, 1934.
7. "Garbage Grinding Plant Installed at St. Louis," *Eng. News-Record*, **144**, 477, April 4, 1935.

CHEMICAL COAGULATION OF SEWAGE*

VII. EFFECT OF GARBAGE

By Willem Rudolfs and Robert S. Ingols

Chief and Assistant, Div. of Water and Sewage Research, New Brunswick, N. J.

Introduction of ground garbage into sewage may conceivably have considerable effect on the coagulation of sewage solids. When garbage is ground, either at the plant or in the home, a certain amount of soluble material is released or squeezed out. Since plant juices are sometimes slightly acid they may aid in coagulation and in turn affect pH adjustment before coagulation. It may also be possible that the quantities of chemicals required will be changed. The soluble garbage materials have a decided biochemical oxygen demand. It has been shown previously (1) that soluble materials are not removed from the sewage liquor, and the question therefore arises, what will happen to the B. O. D. of chemically treated sewage-garbage mixtures? Although laboratory experiments can not be used to determine definitely and exactly the cost of chemicals required, a comparison of cost made on the basis of particular sewages with and without garbage added will show certain relative relationships.

Methods and Procedure

With a "G. E. Kitchen Waste Unit," donated for this and other studies, garbage was ground and mixtures of sewage and ground garbage made in like manner from day to day. Although the kitchen waste unit was regularly filled with garbage and the same amount of water used for grinding, the solids concentration produced varied on account of the variation in texture and volume of material in the hopper of the grinder. The definite quantity of water used served as a means to limit the variations, and only one mixture was made from each sewage for this series of experiments. The ground garbage was thoroughly mixed and then sampled during violent agitation. The quantity of ground garbage added was such that it would amount to 100 per cent or more of the sewage suspended solids. This is approximately the ratio that might be expected when all of a community's garbage is ground and added to the sewers. Conditioning was carried out by a stirring machine with a series of six containers equipped with vertical shaft paddles (2) rotating at 20 r.p.m. Twenty minutes were allowed for flocculation and one hour for settling.

Coagulation at Varying pH Values

In order to obtain a basic understanding of the effect of ground garbage on sewage coagulation, the experiments were extended to

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Div. Water & Sewage Research. (This work was done with the aid of W. P. A. employees.)

study the effect over a wide range, namely from pH 2.0 to pH 11.0. Sulphuric acid was used to obtain values below the original pH of the sewage and sewage-garbage mixtures and lime to raise the pH to 9.5. For pH values above 9.5 a combination of lime and sodium hydroxide was used, that is, lime to adjust to pH 9.5 and NaOH to reach the higher values.

On the assumption that the amounts of solids as garbage produced per capita is about equal to the amounts of suspended solids in sewage, the results reported were based upon 100 per cent additions of garbage. In other words, if a sewage contained 200 p.p.m. total suspended solids, a sufficient quantity of ground garbage was added to make the final suspended solids concentrations about 400 p.p.m. The dilution factor caused by the garbage liquid was ignored because it amounted only to 200 cc. in 20 liters of sewage.

Extended experiments upon the settling of sewage and garbage mixtures have shown that the ground garbage at times would reduce the suspended solids of a settled mixture below that of sewage alone. An example of the effect of pH adjustment on the turbidity removal of a sewage and of a garbage-sewage mixture, where garbage caused turbidity removal, is shown in Fig. 1. The effects and the limits of gar-

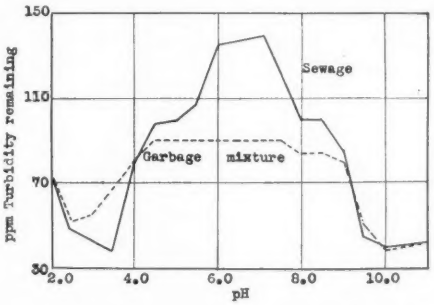


FIG. 1.—Effect of pH on turbidity removal of sewage and garbage mixtures without coagulant.

bage on turbidity removal are strikingly shown by the differences in turbidity remaining in sewage and sewage-garbage mixtures, from pH 4.5 to 8.5. The addition of pH adjusting chemicals to the mixture* between these limits did not cause any greater turbidity removal. At pH 8.0 and 8.5 lime caused some decrease in the turbidity remaining, but not until pH 9.0 was reached did a sharp break occur. At higher pH values the effluents produced from the sewages and mixtures had practically the same turbidity. When the pH was lowered with sulphuric acid a further reduction in turbidity of the mixtures below pH 4.5 occurred, but to a less extent than from the sewage. Although the ground garbage liquor is usually acid in character it is doubtful whether the greater turbidity removal of the mixtures was due to the acid character alone. It is probable that certain plant juices have a

* The term "mixture" indicates "sewage-garbage mixture."

decided coagulating effect. The greater reduction in turbidity of the mixtures above the neutral point (to pH 9.0) indicates that the coagulating effect would be due to the character of the soluble organic substances rather than their powers (acidity) to reduce the pH values.

Since the addition of lime (pH 7.0–9.0) caused a slightly greater removal of turbidity in the mixtures, the plant juices may be considered as more or less specifically acting upon certain suspended materials.

The addition of alcohol causes a coagulation of certain finely divided, semi-soluble or soluble substances. When acetone is added, more and apparently different substances are removed from the liquid. The application of heat produces a different form of coagulation. Since the plant juices come from different sources it is possible that each type of juice acts specifically on a certain group of the substances present in the sewage. Such action would explain why the turbidity removal may remain constant or increase in mixtures when definite quantities of sulphuric acid are added, while with different quantities of acid the effect of the plant juices is obliterated. A discussion of the mechanism of suspended solids removal by different coagulants will appear later in this series.

Some results on the effect of varying dosages of iron coagulants on the coagulation of sewage have been presented previously (3) and for the purpose of demonstrating the effect of a small dosage of ferric chloride over the entire pH range, the results on a sewage and a garbage-sewage mixture are graphically shown in Fig. 2. The amount

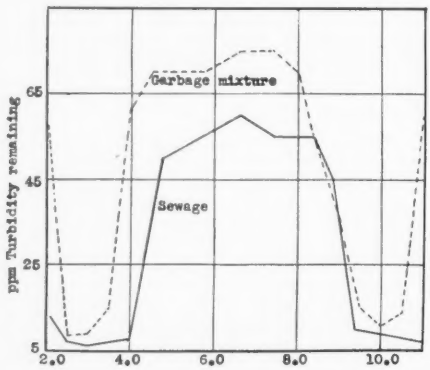


FIG 2.—Effect of pH on turbidity removal with 5 p.p.m. iron.

of ferric chloride used was 5 p.p.m. as Fe and the garbage solids were 100 per cent of the sewage solids. In the example chosen the garbage did not reduce the turbidity of the sewage but caused a greater turbidity. It will be noted that the turbidity remaining after settling of the sewage, without chemical addition (pH 7.0), was in this instance materially lower than that shown in Fig. 1. The results of the mixture shown in Fig. 2 indicate very little turbidity removal between pH 4.5

and 8.0 over the untreated mixture. Beyond pH 8.0 the lime and iron left approximately equivalent amounts of turbidity in both the sewage and mixture, but the material in the mixture re-dispersed at about pH 11.0. In practically the entire acid range the effect of garbage was noticeable, so that either with the same quantity of iron coagulant more acid was needed, or more coagulant with the same amount of acid, to obtain results equivalent to sewage alone. At very low pH values re-dispersion of the mixture was similar to that encountered at high pH values and more pronounced than with sewage.

The effect of ground garbage addition on the coagulation of sewage with commercial alum is shown in Fig. 3. The alum used in this series

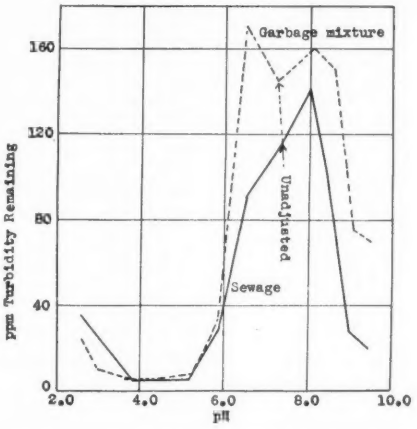


FIG. 3.—Effect of pH on turbidity removal with 5 p.p.m. aluminum.

amounted to 5 p.p.m. as Al. The comparatively strong sewage, when adjusted with a small quantity of lime and coagulated with alum, showed a rise in turbidity. Unpublished results with a number of sewages show that a similar rise in turbidity usually occurs with the addition of small quantities of acids in the presence of alum. The effect of garbage is of interest in this respect, because both on the alkaline and acid side a rise in turbidity was shown.

On the alkaline side, more lime or aluminum is required to obtain the same turbidity removal with garbage mixtures than with sewage alone, but by no means in proportion to the increased amount of suspended solids present. It should be kept in mind that with garbage mixtures, the increase of finely divided suspended solids is not in proportion to the total suspended solids added. Although the garbage is ground, the disintegration of garbage solids is far less complete than of sewage solids. In sewage coagulation the interest centers around the finely divided and colloidal material. For this reason the results with unadjusted liquors must be taken as a basis for comparison.

The effect of the garbage on the acid side is much less pronounced than on the alkaline side, although the coagulation range of the mix-

ture appears to have moved further away from the neutral point. When aluminum is used in the acid range, the equivalent turbidity removal is the reverse of the removal shown with the same quantity of iron. This reversal is by no means constant, as shown later (Fig. 4), but varies with the type of sewage treated. In Figure 4 removals by aluminum in the alkaline range are shown, where more than the equivalent turbidity removal was obtained, and also where equivalent turbidity removals by iron coagulant occurred in the pH range of 8.5 to 9.5. These results are mentioned to indicate the similarities and differences between sewages and sewage-garbage mixtures toward chemical treatment. The general trends of the curves presented indicate that

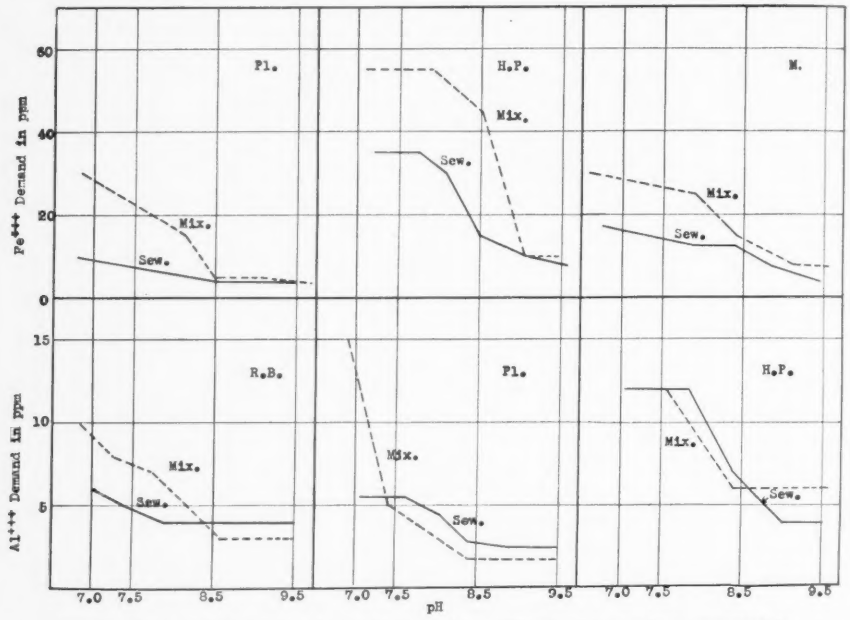


FIG. 4.—Iron and aluminum demands at various pH values to produce comparable turbidity removals.

the behavior of mixtures is the same as sewage when treated with coagulants in conjunction with chemicals used for adjustment, but minor variations depend upon the nature of the garbage and the character of the sewage. In relation to turbidity removals, the addition of garbage to sewage does not cause an appreciable change in the character of chemical coagulation but does cause some quantitative variations in the chemical requirements. The garbage may reduce the suspended solids of the sewage but an additional chemical dosage may be required to produce good clarification.

EFFECT OF PRE-SETTLING

In a previous paper (3) it has been shown that pre-settling of an average sewage was somewhat detrimental to clarification when lime-

iron was used for coagulation, but beneficial when the sewage contained large quantities of settleable solids. Since a considerable portion of the garbage settles rapidly it might be assumed that pre-settling of sewage-garbage mixtures would be of some help in suspended solids removal. However, if the greater clarification of strong sewage depends upon the nature of the suspended solids in the sewage no appreciable aid could be expected.

For the purpose of determining the effect of pre-settling in the presence of ground garbage, a sample of sewage was divided into four fractions. The first fraction (non-settled) was treated with different quantities of iron coagulant, the second settled for one hour and the supernatant used (pre-settled) for coagulation, and the third and fourth fractions made into mixtures and treated similarly as the first and second fractions respectively. Total suspended solids and B.O.D. determinations were used as criteria of the effect of pre-settling. Results on a strong sewage containing 422 p.p.m., and an average sewage with 192 p.p.m. total suspended solids, are given as examples in Table I. These representative samples, containing approximately 100 per

TABLE I.—*Effect of Pre-settling*

	Control			Treated			Treated		
	Fe	Suspended Solids	B.O.D.	Fe	Suspended Solids	B.O.D.	Fe	Suspended Solids	B.O.D.
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Sewage A*									
Non-settled...	0	86	115	40	48	50	—	—	—
Pre-settled ...	0	89	120	40	16	38	—	—	—
Mixture									
Non-settled...	0	78	125	40	86	95	50	23	70
Pre-settled ...	0	104	180	40	78	90	50	6	70
Sewage B†									
Non-settled...	0	78	100	25	19	65	—	—	—
Pre-settled ...	0	98	165	25	38	80	—	—	—
Mixture									
Non-settled...	0	96	187	25	70	135	35	8	85
Pre-settled ...	0	102	195	25	70	145	35	10	98

* Sewage suspended solids, 422 p.p.m., B.O.D. 300 p.p.m.
† Sewage suspended solids, 192 p.p.m., B.O.D. 220 p.p.m.

cent garbage on the basis of suspended solids, show that the addition of garbage to non-settled sewage increased the suspended solids and B.O.D. in the effluent, that pre-settling of strong sewage produced better results with the same amount of chemicals; but that with addition of garbage the effect was much less pronounced. With an average

strength sewage, pre-settling followed by flocculation with or without chemical treatment, resulted in production of effluents with higher suspended solids and much higher B.O.D. The tendency shown in these figures varied in magnitude with the type and character of the sewage used. It appears, therefore, that in chemical coagulation of weak and average sewages, pre-settling of garbage-sewage mixtures before chemical dosage is not of material aid but might be detrimental. Pre-settling of very strong sewage-garbage mixtures may be of some help. The results indicate that the removal of finely divided material in the original sewage presents a far greater problem than that caused by the addition of ground garbage.

Effect on B.O.D.

Rather extensive studies on the effect of garbage on the B.O.D. of the effluent were made in connection with settling, oxidation, and chemical coagulation. Only the results of ground garbage upon the effluent of chemically treated sewage are presented in this paper, but the information obtained in other studies is utilized in the discussion of the work as a background, without presentation of supporting data.

For a comparative study of the effect of ground garbage on the B.O.D. of the effluents, samples of sewages obtained from different sources were subdivided into four fractions. The first fraction was treated to determine the chemical demand, and the range of additions of coagulants was made extensive enough to determine when the demand was exceeded. The first sample showing a turbidity of less than 25 p.p.m. was used as indicating a satisfactory effluent from average and strong sewages, and suspended solids and B.O.D. were determined. A part of the effluent was filtered through filter paper to remove the light suspended solids remaining from the chemical treatment, and the B.O.D. was determined. The filtrate liquor was clear and it was used to eliminate the possible effect of slight variations in suspended solids on the B.O.D. of the various effluents. This was found necessary, because the effluents from the sewages and sewage-garbage mixtures did not contain the same concentration of suspended solids, and small variation in suspended solids might throw doubt upon the B.O.D. results, if similar variations occurred. The B.O.D. results obtained from paper filtrates were taken as representing the highest removals chemical treatment might effect, without an excess of coagulant dosage. To rule out the effect of excess coagulant dosage, the effluent from samples containing excess coagulant was also filtered before B.O.D. determinations were made.

The second fraction of sewage was adjusted to pH 9.5 with lime and the coagulant demand determined. The supernatant was analyzed for suspended solids and B.O.D., paper filtrates were made from effluents with and without excess of coagulant dosage and B.O.D.'s determined. The third and fourth fractions were made into sewage-garbage mixtures, treated similarly to the first and second fractions and the effluents and filtrates analyzed as stated above. On account of the rather

high pH values of the effluent from chemically adjusted sewages and mixtures, seeded B.O.D. water was used.

When it was found in the aluminum coagulant experiments, that the amount of coagulant was not always increased by the addition of ground garbage, these samples were taken for B.O.D. and suspended solids determinations. Part of the original samples were paper filtered, as well as the effluents with excess aluminum dosages, and B.O.D. determinations were made. The same procedure was followed with the mixtures. No pH adjustments were made with different aluminum dosages for this specific investigation. Controls without coagulant or chemical additions were stirred and settled in the same manner as with the chemically treated samples.

Results

The results given are examples of the information obtained and no attempt is made to present detailed evidence of minor variations or figures which may required repetition of statements presented in previous papers of this series.

To demonstrate that chemical treatment produces a certain reduction in B.O.D. of sewage as well as in sewage-garbage mixtures the results of one series are given in Table II, where the sewage and mixtures are compared with and without pH adjustment. The raw sewage used contained 386 p.p.m. suspended solids and 385 p.p.m. B.O.D. Addition of garbage was on the basis of about 100 per cent increase in

Table II.—*Effect of Garbage on B.O.D. with Iron as Coagulant*

	pH	$FeCl_3$ as Fe	Suspended Solids	B.O.D.
		p.p.m.	p.p.m.	p.p.m.
Sewage	7.0	0	62	105
	7.0	30	19	33
	7.0	30	*0*	35
	7.0	35	*0*	33
Sewage, Adjusted	9.5	0	66	120
	9.5	4	7	70
	9.5	4	*0*	65
	9.5	6	*0*	60
Mixture	7.0	0	60	115
	7.0	30	56	65
	7.0	35	34	61
	7.0	35	*0*	61
	7.0	40	*0*	59
Mixture, Adjusted	9.5	0	78	125
	9.5	4	24	110
	9.5	6	20	90
	9.5	6	*0*	90
	9.5	8	*0*	97

0 indicates use of paper filtrate.

total suspended solids. From the results it is clear that an excess of iron coagulant is of no definite help in reducing the remaining soluble B.O.D. of sewages or mixtures. The B.O.D. values of the effluents from lime and iron treated samples were higher than the B.O.D.'s from the samples treated with iron coagulant alone. This holds for both sewage alone or sewage-garbage mixtures. The effect of the garbage on the B.O.D. of the effluents is best shown by samples treated with corresponding quantities of coagulant. The B.O.D. of the mixtures is in each case from 20 to 30 p.p.m. higher than the B.O.D. of the sewage. This relative increase has been noted in all the different mixtures where B.O.D. determinations of chemical effluents were made. Increasing the quantity of coagulant to excess does not lower the B.O.D. values, or in other words the soluble material introduced by the garbage increases the B.O.D. of the effluent whether or not chemical treatment is employed. The increase in suspended solids and B.O.D., using the same iron coagulant dosage for mixtures as for the sewage, may be much more marked than shown by these results. (An example may be found in Table IV.)

An example of the effect of garbage on sewage coagulation when alum is used as coagulant is given in Table III. The results show a

TABLE III.—*Effect of Garbage on B.O.D. of Effluent with Alum as Coagulant*

	Al	Suspended Solids	B.O.D.
	p.p.m.	p.p.m.	p.p.m.
Sewage	0	80	175
	10	20	54
	10	*0*	52
	12.5	*0*	41
Mixture	0	115	270
	10	30	134
	10	*0*	138
	12.5	*0*	138

greater rise in B.O.D. of chemical effluents with alum than with iron, when ground garbage has been added to the raw sewage, although clarification was not greatly affected. It is of interest in this respect, that without chemical adjustment the aluminum demand of the mixture was not materially greater than of the sewage, although the B.O.D. of the effluents was markedly increased.

The increase in B.O.D. of the effluents is caused by the "soluble" material added with the ground garbage. The term "soluble material" is used to indicate those substances present in the clarified liquid passing through a filter paper. This conception is not theoretically correct, because any colloidal substances not removed by the coagulant may pass through filter paper, unless held by adsorption on the surface or interstices of the paper. From a practical standpoint, the substances present in the clear liquor have been considered as soluble in

order to determine the relative relationship between the total suspended solids and the material present in the effluent. Averaging ten different sewages and ten sewage-garbage mixtures, the increase in suspended solids and B.O.D. of the settled sewage and mixtures, and the B.O.D. of the "soluble" fraction in the chemical effluents were as follows:

	Sewage P.p.m.	Mixture P.p.m.	Increase in Mixture	
			P.p.m.	Per Cent
S.S. in settled	88.2	90.5	2.3	3
B.O.D. in settled	121.3	167.7	46.9	38
B.O.D. of "soluble" part	33.2	68.8	35.6	106

The average increase in suspended solids is negligible. As stated before, sometimes garbages caused a considerable reduction in suspended solids of the sewage, whereas at other times the suspended solids were increased. The reduction or increase may vary from 25 to 50 p.p.m. depending upon the character of the sewage and the nature of the garbage.

Although the garbage addition to the sewage in the form of suspended solids amounted to about 100 per cent, the B.O.D. of the mixture increased on an average only 38 per cent, but the "soluble" B.O.D. increased by 106 per cent. Stating it differently, the results show that 77 per cent of the material which caused a rise in the B.O.D. of the settled effluent was soluble, whereas the soluble B.O.D. of the sewage was only 27 per cent of the B.O.D. of the settled sewage.

A material increase in soluble B.O.D. is of considerable importance in chemical treatment when the treatment is intended to relieve the load on a river. The substances causing the increased B.O.D. have a rapid demand for oxygen which can not be removed by coagulation or filtration. Even excess of coagulant, added either in the form of iron or aluminum, does not decrease the soluble B.O.D.

Comparative Chemical Demands

In studying the effect of garbage on sewage coagulation one of the more interesting phases deals with the increased quantity of coagulant required when garbage is added. To make the conclusions more general, a number of sewages obtained from different municipalities and varied types of garbage were collected and experimented with by several methods. One series of experiments was conducted with sewages collected from different sources, but with addition of the same amount of the same garbage. In this work the iron demand of each sewage and its garbage mixture was determined. The effluents from the garbage mixtures, which were treated with the amounts of iron coagulant necessary to satisfy the iron demand of the sewage to which

the garbage was added, were analyzed for suspended solids and B.O.D. after mixing, coagulation and settling. Further information on the effect of garbage on the B.O.D. of the effluents was obtained by analyzing paper filtrates and Seitz filtrate. In addition to the work on effluents, comparative iron and aluminum demands were made using turbidity measurements of the effluents as criteria of efficiency. A turbidity of 30 p.p.m. or less was considered necessary for clarified sewage and the least amount of chemical to produce this results as the chemical demand.

During the early stages of the work it was found that it was difficult to predict the chemical demand of the sewage-garbage mixtures even when the demands of the sewages were already known. These variations were apparently related to the staleness of the sewage. As an example, two fresh sewages from Highland Park and New Brunswick were compared with a stale sewage from Plainfield (Table IV).

TABLE IV.—*Effect of Garbage on Fresh and Stale Sewage*

	Fe	Sewage Effluent		Mixture Effluent	
		Suspended Solids	B.O.D.	Suspended Solids	B.O.D.
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Highland Park	0	60	110	86	140
	35	37	50	114	120
	40	*0*	36	83	97
	45	—	—	53	77
	50	—	—	*0*	72
New Brunswick	0	158	135	82	165
	20	45	70	106	155
	25	*0*	70	82	110
	30	—	—	42	95
	35	—	—	*0*	95
Plainfield	0	124	180	126	230
	15	12	97	152	200
	20	*0*	70	110	180
	35	—	—	7	135
	40	—	—	*0*	110

0 = paper filtrate.

The same garbage in equal quantities was added to each sewage. The raw sewages had the following suspended solids and B.O.D. in p.p.m:

	Suspended Solids	B.O.D.
Highland Park	216	235
New Brunswick	246	210
Plainfield	354	440

The results in Table IV show that the Highland Park and New Brunswick sewages required more coagulant to produce a clear effluent than the Plainfield sewage. This brings out the point in question more clearly. The sewages from the former two municipalities required 10 p.p.m. additional coagulant to produce an effluent containing a given amount of suspended solids, whereas the Plainfield sewage required an additional 20 p.p.m. coagulant. In all cases the remaining B.O.D. in the effluent of the garbage mixtures was higher, even with excess quantities of coagulant. The increase in B.O.D. of the mixtures treated with the highest chemical dosages to produce a clear effluent, when filtered, amounted to 25 to 40 p.p.m. Seitz filtrates were practically the same as paper filtered effluents. For instance, coagulated sewage effluent with 50 p.p.m. B.O.D. showed a Seitz filtrate of the settled sewage of 47 p.p.m. B.O.D., and the garbage-sewage mixture 77 and 80 p.p.m. respectively. This indicates again that the B.O.D. increase caused by the garbage is mainly in a soluble form. However, the rise in B.O.D. of the chemical effluents appears to be rather constant. An analysis of available data, using eight different sewages and their mixtures, showed that four sewages, treated with equal amounts of garbages whose liquors had an average B.O.D. of 3000 p.p.m., exhibited an average B.O.D. increase of 33 p.p.m. in the effluent, whereas four other sewages to which equivalent amounts of garbage were added with an average B.O.D. of 12,000 p.p.m. in the liquor, showed only 27 p.p.m. increase in their chemical effluents. The results indicate that the increase in B.O.D. in chemical effluents is comparatively independent of the B.O.D. of the ground garbage. Ground garbages with high B.O.D. values have high coagulation factors when mixed with sewage. The necessity for higher quantities of coagulant removes in part the material causing the higher B.O.D. Since the B.O.D. of the ground garbage is influenced by the type of the garbage and the method or degree of grinding, effluents from settling tanks will be affected differently. In the case of chemical treatment the effluents are not affected by the variations in the garbage or its grinding when quantities are added equivalent to approximately 100 per cent of the dry suspended solids of the sewage, because the chemical dosage is the important factor. This does not mean that large quantities of the same garbage ground in the same manner do not have a greater effect than small quantities of garbage added. When the B.O.D. of the effluent of a settling tank increases from 20 to 25 p.p.m. with an addition of 50 per cent of garbage solids, an increase of from 40 to 50 p.p.m. may be expected when the garbage is increased to 100 per cent.

During the study of aluminum coagulation it was felt that more information could be gained by a greater variety of tests. Determinations of suspended solids in the effluents were considered sufficient in this part of the investigations. To determine the effect of garbage on sewage coagulation and the effect of staleness of sewage upon the aluminum requirements, three sewages from different sources were mixed with equal amounts of the same garbage. The results obtained

are shown in Table V. The effect of garbage on clarification by aluminum varied with the sewage. The aluminum demand of garbage-sewage mixtures increased over sewage alone but not in proportion to the suspended solids added. Staleness of the sewage caused as a rule an increase in aluminum demand. When garbage-sewage mixtures were treated with equivalent quantities of aluminum sufficient to produce good clarification in sewage alone, the suspended solids remaining were at times higher than when the mixtures were untreated. This may be quite important in plant practice. Under certain conditions, garbage addition does not cause an increase in aluminum demand sufficient to produce equivalent turbidity and suspended solids removal.

TABLE V.—*Effect of Garbage in Alum Treatment*

	Alum as Al	Suspended Solids		
		N.B.	Pl.	H.P.
	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Raw Sewage	—	130	394	282
Sewage Effluent	0	42	42	50
	5	6	38	52
	7.5	—	5	48
	10	—	—	8
Mixture Effluent	0	48	46	56
	5	70	56	60
	7.5	6	76	64
	10	—	32	56
	12.5	—	7	28

When iron was used as coagulant, the iron demand always increased when garbage was added. The fact that a difference appeared to be present between the two coagulants led to a study to determine whether there was any relation between the iron and aluminum demand of the same sewages when the same garbage was added. For comparison a series of tests were made with sewage-garbage mixtures showing either no increase or some increase of aluminum demands, and these mixtures were treated correspondingly with iron coagulants. Some of the condensed results are given in Table VI. The examples given show a variety of conditions; they include sewage with high and low suspended solids remaining, sewage with comparatively high and low coagulant demands, sewages from which more solids are removed upon settling by the addition of garbage, and sewages showing increased suspended solids remaining upon settling after addition of garbage.

In all experimental work the ferric iron demand of the mixtures has been greater than of the sewage. With aluminum, the coagulant demand varies. The results given show that the quantity of iron coagulant required for good clarification of sewage has no relation to the increase in iron demand when garbage is added, neither has the iron

demand or the magnitude of the iron demand of sewage or sewage-garbage mixtures any definite relation to the aluminum demand. For instance, in one sewage the increase in iron demand caused by garbage amounted to 8 p.p.m. and the aluminum demand increase to 2.5 p.p.m., whereas in another sewage the garbage mixture showed an increase of 16 p.p.m. in iron demand and no increase in aluminum demand. This

TABLE VI.—*Sewages and Mixtures with Stationary or Increased Aluminum Demand Compared with Increasing Iron Demands*

Coagulant	None	$FeCl_3$		$Al_2(SO_4)_3$†		None	$FeCl_3$		$Al_2(SO_4)_3$*	
	Turb.	as Fe	Turb.	as Al	Turb.	Turb.	as Fe	Turb.	as Al	Turb.
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Sewage effluent	105	16	20	7.5	15	115	24	20	10	25
Mixture effluent	175	16	75	7.5	70	240	24	45	10	30
Mixture effluent	175	24	20	10	15	240	30	15	—	—
Sewage effluent	125	25	25	10	20	90	20	20	10	20
Mixture effluent	100	25	60	10	45	115	20	55	10	20
Mixture effluent	100	35	25	12.5	20	115	30	20	—	—
Sewage effluent	165	35	25	12.5	20	200	30	25	12.5	10
Mixture effluent	170	35	125	12.5	45	165	30	65	12.5	20
Mixture effluent	170	55	20	15	15	165	40	20	—	—

* No increased demand.

† Increased demand.

holds as well for sewage-garbage mixtures made from different sewages with the same garbage as for the same sewage to which different types of garbage were added.

Apparently the addition of chlorinated copperas to sewage-garbage mixtures is similar to the addition of ferric chloride coagulant, in respect to increased quantities required. As an example the results of a series are given in Table VII, where the effect of garbage is shown.

TABLE VII.—*Effect of Garbage on Iron Coagulants as Compared with Aluminum*

Coagulant	None	$FeCl_3$		$FeSO_4Cl$		$Al_2(SO_4)_3$
Fe or Al, p.p.m.	0	16	32	20	35	12.5
Turbidity, Sewage, p.p.m.	90	25	—	25	—	20
Turbidity, Mixture, p.p.m.	95	75	25	45	20	20
Increase Demand, p.p.m.	—	—	16	—	15	0

All samples were subjected to the same time of stirring and settling. The addition of garbage in this instance caused very little increase in suspended material after settling. In a subsequent paper an attempt will be made to explain the mechanism of coagulation and the probable reasons for the difference in behavior of aluminum.

It is evident that the iron demand of the sewage will be increased by the addition of ground garbage. How much the iron demand will increase depends upon the sewage and garbage characteristics, but

an increase of at least from 5 to 10 p.p.m. Fe can be expected. This is a comparatively small increase when compared with the rather large iron demands of some of the sewages worked with, but in some instances may amount to an increase of 100 per cent or more. On the other hand an increase in the aluminum demand occurs irregularly. Since chemicals constitute a considerable part of the cost of chemical treatment processes an attempt has been made in the following section to determine the relative cost of sewage-garbage mixtures coagulation as compared with sewage alone.

Relative Cost

The relative cost determination of chemicals used for coagulation is not presented with the idea that the sewages obtained from the different municipalities can be treated for the amounts of money given, nor to indicate what sewage coagulation costs would be under a variety of conditions, but solely for the purpose of indicating what relative increase in cost of chemical can be expected when garbage is added to such sewages and different coagulants are used. The relative cost estimates for chemicals deal only with ferric chloride and lime, and aluminum and lime when these are added to sewage and sewage-garbage mixtures.

The sewages used varied in suspended solids, but may be considered as average to fairly strong. The raw sewage of the examples reported for ferric chloride treatment contained H.P. 248 p.p.m., P. 320 and M. 220 p.p.m. suspended solids, whereas the raw sewages chosen as examples for alum treatment had H.P. 336 p.p.m., P. 350 and R.B. 232 p.p.m. suspended solids.

After determining the iron and aluminum demands of the sewage and the sewage-garbage mixtures, samples were adjusted to different pH values, the coagulant demands again determined and quantities of iron and aluminum coagulants added to produce effluents with approximately the same turbidity of less than 30 p.p.m. Adjustment of the pH values of sewage and mixtures were made at increments of 0.5 and coagulant additions with differences of 1 to 2 p.p.m. Fe or Al between samples. Standardized iron and aluminum coagulants were made freshly for each series of experiments and lime suspensions were made from sifted lime. The quantities of lime and coagulants required for equivalent results at the different pH values were then calculated in pounds per million gallons of sewage and of mixtures. Since the study was intended for the determination of relative cost of treatment of sewage and sewage-garbage mixtures, the actual cost of the lime and coagulants was of less importance, than obtaining an idea of the percentage increases: therefore, the cost of the chemicals was taken from current local quotations, namely: lime as 100 per cent CaO at 0.6c per lb., $FeCl_3$ as Fe (in tank cars) at 7.35c and commercial alum as Al (in ton lots) at 8.0c per lb.

The cost of iron coagulant requirement to produce equal clarification with sewage and sewage-garbage mixtures over a pH range from 7.0 to 9.7, together with the cost of lime is shown in Fig. 5 for three different types of sewage obtained from various communities. Alongside are plotted the total chemical costs for the same sewages and mixtures at different pH values. It is evident that the cost for iron

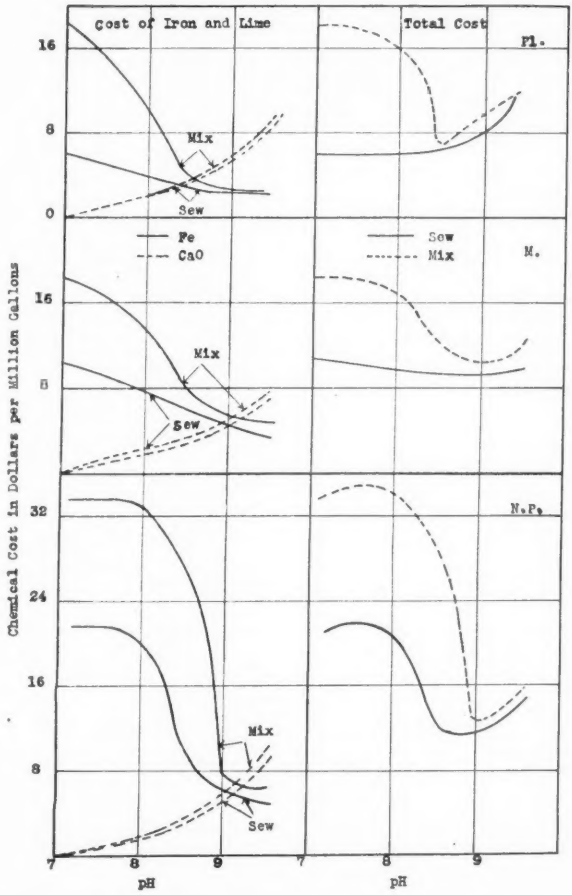


FIG. 5.—Cost of different sewages and their garbage mixtures for treatment by $FeCl_3$ and lime.

coagulants increases over the entire pH range shown, when garbage is added. The iron requirements for the mixtures decrease more rapidly when the optimum coagulation points are approached than for sewages alone. As could be expected the lime requirements for mixtures are only slightly higher than for sewage. The total cost for chemicals used for adjustment and coagulation is higher for mixtures

than sewage, but the difference in cost is rather small around the optimum coagulation points. In this respect it is of considerable interest that the cost of iron requirement with the best pH values for coagulation is about the same as the cost of lime, both for sewage and garbage mixtures. The best coagulation point varies with the character of the sewage and subsequently the lowest cost over the entire pH range

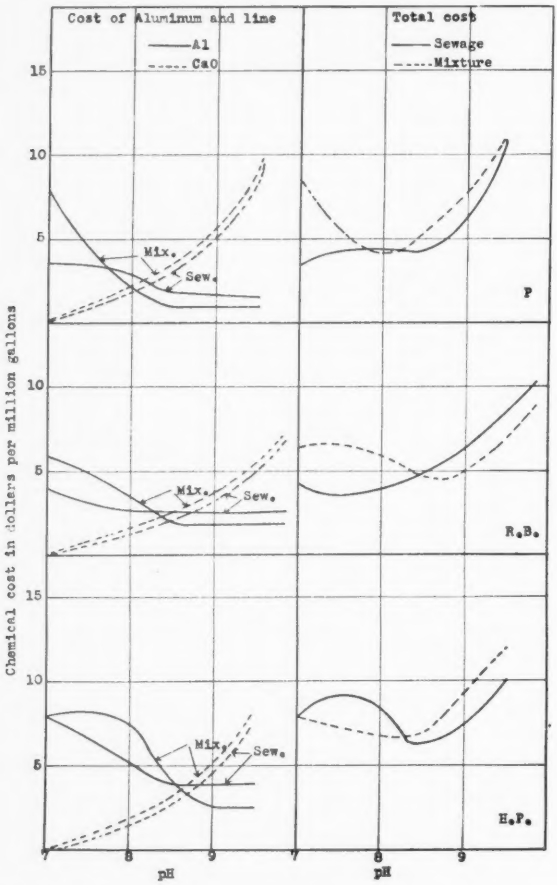


FIG. 6.—Cost of different sewages and their garbage mixtures for treatment with alum and lime.

varies with the sewage, while the second factor affecting the lowest cost is the type of garbage.

Similar experimental results, with alum as coagulant, calculated for a comparative cost analysis are shown in Fig. 6. The relative lime requirements for sewage and garbage did not differ greatly. At certain pH values the alum requirement for equivalent clarification of mixtures was somewhat greater than for sewage, while at other pH

values it was less. This was also the case when the total cost is taken for comparison.

Many factors must be considered when a coagulant for sewage treatment is selected, but if the factor of cost of coagulant alone can be considered it appears that alum may be less expensive than ferric chloride to produce equivalent clarification results when ground garbage is added to sewage. This is indicated when the minimum increase in cost caused by garbage addition is considered. For lime and ferric chloride the minimum additional cost of chemicals varied for the different sewages from \$0.60 to \$1.00 per million gallons, whereas the minimum increase in cost for lime and alum treatment varied from \$0.45 to \$0.60 per million gallons. Part of the lower minimum cost increase is due to the fact that the optimum point of coagulation with alum is lower than for ferric chloride, so that less lime for reaction adjustment is needed. Best results with ferric chloride coagulant for garbage-sewage mixtures were obtained at pH values of 9.0 to 9.5, whereas similar results with alum as coagulant were obtained at pH values between 8.5 and 9.0.

The results presented on the effect of garbage on the B.O.D. of the effluent indicate that reasonable dosages of neither alum or ferric chloride removes the "soluble" B.O.D. introduced with the garbage and that the remaining B.O.D. is about the same with either coagulant. For this reason only clarification was considered when relative cost estimates were given. Since clarification is affected differently by the character of the sewage and type of garbage, and the type of coagulant is also a factor, better results may be obtained with ferric chloride at one place and with alum at another. The fact remains, however, that the addition of garbage causes only a comparatively small increase in chemical demand and consequently the cost for chemicals is in no way proportional to the increase in suspended and soluble solids added when ground garbage is mixed with sewage. The increase in cost is but a fraction of the total cost for chemicals required.

Summary

Experiments to determine the effect of ground garbage on the clarification and B.O.D. of effluents when chemicals are used for pH adjustment and coagulation, show that the addition of garbage may cause a greater or smaller removal of suspended solids. The reduction of suspended solids is affected by the character of the sewage, the nature of the garbage and the type of coagulant. Although suspended solids may not increase, the soluble B.O.D. in the effluent increases about 100 per cent. Pre-settling of strong garbage-sewage mixtures may be of some help in clarification, but pre-settling of weak and average sewage-garbage mixtures before chemical dosage is not of material aid and might be detrimental. The addition does not cause an increase in chemical coagulant proportional to the amount of suspended solids added. The ferric iron demand of garbage-sewage mix-

tures is greater than of sewage alone, but with alum coagulant it may or may not be greater. The magnitude of the iron demand has no relation to the increase in iron demand of the sewage or mixtures and the iron demand has no relation to the aluminum demand.

The addition of garbage causes only a comparatively small increase in chemical cost, amounting to only a fraction of the total cost required for chemicals.

REFERENCES

1. Rudolfs and Gehm, *This Journal*, **8**, 537 (1936).
2. Rudolfs and Gehm, *This Journal*, **8**, 195 (1936).
3. Rudolfs and Gehm, *This Journal*, **8**, 422 (1936).

Editor's Note.—Word has been received from Dr. Rudolfs just before going to press that the estimates of cost of alum are too low. Correction to current quotations will be published in the next issue (July).

THE "SLOPE" METHOD OF EVALUATING THE CONSTANTS OF THE FIRST-STAGE BIOCHEMICAL OXYGEN-DEMAND CURVE

By Harold A. Thomas, Jr.

Assistant in Sanitary Engineering, Harvard Graduate School of Engineering, Cambridge, Mass.

In an earlier publication from the Department of Sanitary Engineering of Harvard University, a simplified procedure for the determination of the constants of the first-stage biochemical oxygen demand was presented by Fair.[1] At the suggestion of Professor Fair, the author wishes to describe a new approach to this problem which he has named the "slope" method. This method appears to be fully as simple as the "log-difference" method of Fair and to yield values appreciably closer to those obtained by the Reed and Theriault procedure.

Development of the first-stage biochemical oxygen demand of polluted water as a unimolecular reaction is based on the following differential equation:

$$\frac{dy}{dt} = k'(L - y) \tag{1}$$

Here y = B.O.D. exerted in time t,
L = Ultimate B.O.D. of first stage,
k' = Reaction velocity constant,
$\frac{dy}{dt}$ = Increase in B.O.D. per unit time at time t.

This equation readily integrates into:

$$y = L(1 - 10^{-kt}) \tag{2}$$

where $k = 0.4343\ k'$. This is the form in which the reaction is commonly expressed.

The statistical treatment of reaction velocity data heretofore has been evolved from this integrated form of the equation. A method has been devised by Reed and Theriault [2] following the conventional pattern of linearizing a transcendental equation such as (2) by assuming a trial value of k and using the first term of a Taylor's expansion in a least squares treatment. Such methods undoubtedly give the most consistent and in general the most accurate results. Unfortunately the calculations involved are somewhat long and cumbersome. Moreover, the computations may have to be repeated because of the selection of a trial value of k which was not sufficiently near the true value.

In order to eliminate much of the laborious computation, and to avoid the necessity of assuming trial values of k, the author proposes a simplified method for the evaluation of the constants of a unimolecular equation. This method is based entirely upon a least squares treatment of the differ-

ential equation (1) of the reaction. The approach deals with the rate of change of y, which is the slope of equation (2). Hence it may be called the "slope" method. The treatment is readily adaptable to data gathered at irregular time intervals and is not confined to positive rates of change of y with time. It is felt that a simplified approach to the problem of computing L and k will stimulate a more general use of these important parameters. An attempt to reduce the amount of computation without imposing narrow restrictions as to the range of applicability of the calculations constitutes a step toward sound formulation.

Normal Equations for Finding L and k.—The differential equation $dy/dt = k'(L - y)$, it is seen, is linear between dy/dt and y. (For convenience dy/dt will be expressed in its common abbreviated form y'.) With this linear equation the expressions for L and k follow from the usual least squares procedure. This treatment requires that the sum of the squares of the n residuals, $R = Lk - ky - y' = a + by - y'$, be a minimum. This is expressed mathematically as $\Sigma R^2 = \Sigma(a + by - y')^2 =$ a minimum.

In order that ΣR^2 be a minimum, the following criteria must be satisfied:

$$\frac{\partial \Sigma R^2}{\partial a} = 0 \qquad \text{and} \qquad \frac{\partial \Sigma R^2}{\partial b} = 0$$

That is:

$$\Sigma R \frac{\partial R}{\partial a} = 0$$

$$\Sigma(a + by - y') \times (1) = 0$$

or

$$na + b\Sigma y - \Sigma y' = 0 \tag{3}$$

Similarly:

$$\Sigma R \frac{\partial R}{\partial b} = 0$$

$$\Sigma(a + by - y') \times (y) = 0$$

or

$$a\Sigma y + b\Sigma y^2 - \Sigma yy' = 0 \tag{4}$$

Equations (3) and (4), known as the normal equations, simultaneously yield values of a and b from which L and k' are obtained directly by the relations: $k' = -b$ and $L = -a/b$.

The calculations include determinations of y', $y'y$ and y^2 for each value of y. The summation of these gives the quanties $\Sigma y'$, $\Sigma y'y$ and Σy^2 required by the normal equations (3) and (4).

It is necessary to develop values of dy/dt from the given data of y and t. This is accomplished by means of the following relation:

$$\frac{dy}{dt} = y' = \frac{(y_2 - y_1)\left(\frac{t_3 - t_2}{t_2 - t_1}\right) + (y_3 - y_2)\left(\frac{t_2 - t_1}{t_3 - t_2}\right)}{(t_3 - t_1)}$$

where dy/dt is the rate of change of B.O.D. at t_2. y_1, t_1; y_2, t_2; and y_3, t_3 are any successive pairs of the given data, y and t. This formula, though somewhat formidable in appearance, is in reality quite simple in its application. It may be solved either mentally or by the slide rule.

For the special case of equal time increments $t_3 - t_2 = t_2 - t_1 = \Delta t$, equation (5) reduces to

$$\frac{dy}{dt} = \frac{y_3 - y_1}{2\Delta t}.$$

Here as before dy/dt is the slope of the curve at y_2 and t_2. These formulae were developed by computing the actual slope of a second degree curve (parabola) at the point y_2, t_2 which coincided with the given data at points y_1, t_1; y_2, t_2; and y_3, t_3.

Two examples have been included to illustrate the application of the method to typical B.O.D. studies. All calculations are simple and direct. In nearly all cases the accuracy of the slide rule or of four-place logs is sufficient to give three significant figures in the values of L and k. A minimum of six observations of y and t are usually necessary to give consistent results.

Example 1: Equal Time Increments.

*Data from Theriault's Incubation Tests on Unfiltered Ohio River Water**

t (1)	y (2)	y' (3)	$y'y$ (4)	y^2 (5)
0.....	0	—	—	—
1.....	0.705	0.530†	0.374	0.497
2.....	1.06	0.418	0.443	1.124
3.....	1.54	0.320	0.493	2.372
4.....	1.70	0.170	0.289	2.890
5.....	1.88	0.205	0.385	3.534
6‡.....	2.11‡	0.215	0.454	4.452
7.....	2.31	0.155	0.358	5.336
8‡.....	2.42‡	0.095	0.230	5.856
9‡.....	2.50‡	0.075	0.187	6.250
10.....	2.57			
Sums	16.225	2.183	3.213	32.311

(1) Time in days.
(2) B.O.D. observed in stated time.
(3) Rate of change of B.O.D. (B.O.D. per unit time.)
(4) Column (2) × Column (3).
(5) Column (2) squared.

* Reference (2) p. 122, Series No. 7, 20° C.

† $y_n' = \frac{y_{n+1} - y_{n-1}}{t_{n+1} - t_{n-1}} = \frac{1.06 - 0}{2 - 0} = 0.530$

‡ Values interpolated graphically to secure equal time increments.

Writing normal equations

$$\text{I} \quad na + b\Sigma y - \Sigma y' = 0$$
$$9a + 16.225b - 2.183 = 0$$
$$\text{II} \quad a\Sigma y + b\Sigma y^2 - \Sigma yy' = 0$$
$$16.225a + 32.311b - 3.213 = 0$$

$$\text{I} \times \frac{16.225}{9} = \text{III} \quad 16.225a + 29.2506b - 3.935 = 0$$

$$\text{II} - \text{III} \quad 3.061b + 0.722 = 0$$

$$-b = k' = 2.3026k = \frac{0.722}{3.061} = 0.2359$$

$$k = \frac{.2359}{2.3026} = 0.1025 \text{ per day}$$

$$a = \frac{1}{9}[16.225(.2359) + 2.183] = \frac{6.010}{9} = .66778$$

$$L_a = \frac{a}{k'} = \frac{0.66778}{0.2359} = 2.831.$$

Example 2: Unequal Time Increments

*Data from Theriault's Incubation Tests on Unfiltered Ohio River Water**

t	Δt	y	Δy	y'	yy'	y^2
0		0.0				
	1		0.80			
1		0.80		0.725	0.579	0.640
	1		0.65			
2		1.45		0.583†	0.846	2.102
	.875		0.46			
2.875		1.91		0.486	0.929	3.648
	2.125		0.83			
5		2.74		0.308	0.843	7.508
	1		0.27			
6		3.01		0.250	0.753	9.060
	1		0.23			
7		3.24		0.205	0.664	10.498
	1		0.18			
8		3.42		0.163	0.558	11.696
	2	—	0.26			
10		3.68				
		16.57		2.720	5.172	44.972

* Reference (2) p. 120, Series No. 6, 20° C.

† $$y_n' = \frac{(y_n - y_{n-1})\frac{t_{n+1} - t_n}{t_n - t_{n-1}} + (y_{n+1} - y_n)\left(\frac{t_n - t_{n-1}}{t_{n+1} - t_n}\right)}{t_{n+1} - t_{n-1}}$$

$$= \frac{(\Delta y)_{n-1}\left(\frac{\Delta t_{n+1}}{\Delta t_{n-1}}\right) + (\Delta y)_{n+1}\left(\frac{\Delta t_{n-1}}{\Delta t_{n+1}}\right)}{(\Delta t_{n-1}) + (\Delta t_{n+1})} = \frac{(0.65)\left(\frac{.875}{1.00}\right) + (0.46)\left(\frac{1.00}{.875}\right)}{1 + 0.875} = 0.583$$

Writing normal equations

$$\begin{aligned} & na + b\Sigma y - \Sigma y' = 0 \\ \text{I} \quad & 7a + 16.57b - 2.720 = 0 \\ & a\Sigma y + b\Sigma y^2 - \Sigma yy' = 0 \\ \text{II} \quad & 16.57a + 44.972b - 5.172 = 0 \end{aligned}$$

$$\text{I} \times \frac{16.57}{9\,7} = \text{III} \quad 16.57a + 39.2216 - 6.438 = 0$$

$$\text{II} - \text{III} \quad 5.751b + 1.266 = 0$$

$$-b = k' = 2.3026k = \frac{1.266}{5.751} = 0.220$$

$$k = \frac{0.220}{2.3026} = 0.0956 \text{ per day}$$

$$a = \frac{1}{n}[-b\Sigma y + \Sigma y'] = \frac{1}{7}(0.22)(16.57) + 2.720 = 0.9093$$

$$L = \frac{a}{K} = \frac{0.9093}{0.220} = 4.130$$

The values of $L = 2.831$ and $k = 0.1025$ in example 1 are respectively within 0.07 per cent and 0.49 per cent of the values $L = 2.833$ and $k = 0.1030$ obtained by the Reed-Theriault treatment. In example 2 the discrepancies amount to 1.12 per cent in the case of L and 3.24 per cent in the case of k.

It is understood that certain approximations are involved in the slope method. These are introduced: (*a*) in the evolution of dy/dt and (*b*) in the substitution of the most probable slope calculated from observed y's for the most probable value of y calculated from observed t's. Of these, approximation (*a*) has been shown to be of considerably less magnitude than the experimental errors in the determination of y. Approximation (*b*), on the other hand, constitutes not so much an approximation as a different avenue of approach to the problem.

A large amount of experimental data, including that in Public Health Bulletin 173,[3] has been computed by the slope method. It is seldom that the values of L and k obtained vary by more than 5 per cent from those given by the method of Reed and Theriault. Usually the variation is within 1 to 3 per cent and not infrequently the values obtained by the simplified method check exactly with those of Reed and Theriault.

Conclusion

The "slope" method of evaluating the reaction velocity k and the ultimate first stage demand L, in a single computation, employing a least squares determination of the most probable slope of a unimolecular

reaction equation has been presented. The method is simple and in general is solved by means of the slide rule in fifteen to twenty minutes. That it is consistent and generally applicable has been shown by extensive trial on various experimental data.

In closing the author wishes to thank Professor Fair for his advice on the salient points of the analysis.

References

1. Gordon M. Fair, "Log-Difference'" Method of Estimating the Constants of the First-Stage Biochemical Oxygen-Demand Curve." *This Journal*, May, 1936.
2. Lowell J. Reed and E. J. Theriault, "The Statistical Treatment of Velocity Data." *J. Phys. Chem.*, **35**, 673–689, 950–971 (1931).
3. E. J. Theriault, "The Oxygen Demand of Polluted Waters," *Pub. Health Bull.* **173**, 174–185, (1927).

II. FACTORS INFLUENCING THE CLARIFICATION OF SEWAGE BY ACTIVATED SLUDGE *

By H. Heukelekian

Associate, Division Water and Sewage Research, New Brunswick, N. J.

For the purpose of this paper, clarification will be considered a phenomenon distinct and different from the oxidation phase of purification of sewage by activated sludge. An attempt will be made to study this phenomenon as an entity by determining the effect of some of the factors which influence it. The sludge-sewage mixtures were subjected to various experimental conditions in the laboratory and their effect on the turbidity of the supernatant was determined. The turbidity is considered as the best parameter for the clarification stage.

Effect of Air, Nitrogen Gas and Stirring

Returned sludge (from Hillsdale, N. J., activated sludge plant) was mixed (20 per cent by volume) with cotton-filtered sewage. A portion of the mixture was placed in an open battery jar and the mixture was stirred in a stirring machine (horizontal paddles, 20 r.p.m.) while another portion was aerated in a glass tube with diffused air. The turbidities of the supernatant liquors (after ½ hour sedimentation) were as follows:

	Turbidities, P.p.m.	
Time	Stirred	Aerated
Initial	145	140
½ hour	140	100
1 hour	115	75

Stirring for one hour brought about a small amount of clarification while with aeration clarification was much more rapid.

Air absorption was not excluded through the open surface of the battery jar during stirring. It was thought that the observed clarification with stirring might be due to the air introduced through the open surface. A comparison was therefore made on the clarification effected by air, stirring and nitrogen gas.

One mixture of activated sludge (Hillsdale) and sewage was aerated, another was agitated in a cylinder with nitrogen gas, and a third portion was stirred in the stirring machine. The turbidities of the supernatant liquors were as follows:

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J. Div. Water and Sewage Research.

Hours	Turbidities, P.p.m.		
	Air	N Gas	Stirring
0	150	150	150
½	110	120	115
1	100	125	110
1½	90	130	100
2	80	130	100

Best clarification was obtained by passing a stream of air through the mixture and the poorest with nitrogen gas, stirring giving intermediate results. Clarification with nitrogen gas was not progressive. After the initial clarification there was no further improvement but instead a slight deterioration. The initial effect might be attributed to the clarifying power of the sludge maintained from the previous aeration.

Two similar comparisons with sludge obtained from another plant (Madison-Chatham) did not indicate even the slight improvement by nitrogen gas that was obtained with the sludge from Hillsdale. This is indicated by the figures below, where the results for turbidity are given:

Hours	Series II		Series III	
	Turbidities, P.p.m.			
	Air	N Gas	Air	N Gas
0	150	150	120	140
1	70	170	60	200
2	50	190	45	200
3	45	190	40	210

Effect of Treatment with Sewage and Water on the Clarifying Power of Activated Sludge

A portion of returned sludge from Hillsdale was washed with water and another portion with sewage. One liter of sludge was treated five times with 6 liters of sewage or water. After each washing the sludge was allowed to settle and the supernatant was drawn off. The sludges obtained after the fifth washing and the original untreated sludge were each mixed with cotton-filtered sewage and stirred in a stirring machine. The turbidities of the supernatant liquids after different periods of mixing were as follows:

Hours	Turbidities, P.p.m.		
	Washed with Sewage	Washed with Water	Not Washed
Initial	155	140	135
½ hour	120	95	100
1 hour	100	90	95

Treating the sludge thus with thirty volumes of sewage retarded somewhat the clarifying power of the sludge. Washing the sludge with water had little effect on its clarifying power.

The experiment was repeated with returned sludge from the Morristown plant. In four successive washings 66 liters of sewage or water per liter of sludge were employed. The effect of this treatment on the removal of turbidity by stirring is given below:

Hours	Turbidities, P.p.m.		
	Washed with Sewage	Washed with Water	Not Washed
Initial	165	110	140
½ hour	165	105	115
1 hour	160	95	110

The clarifying power of the sludge was destroyed when washed with these quantities of sewage. Portions of each of the above sludges were aerated for 24 hours and at the end of this period the clarification of sewage by the different sludges determined as previously. The turbidities of the supernatant liquor after stirring were as follows:

Hours	Turbidities, P.p.m.		
	Washed with Sewage	Washed with Water	Not Washed
Initial	120	110	115
½ hour	120	95	95
1 hour	120	85	85

The clarifying power of the sewage-treated sludge was not restored by 24 hours of aeration.

Character of the Floc Separated by Washing

It was observed in the washing experiments that when sewage was employed the turbidity of the supernatant was higher than the turbidity of the sewage even after the fourth washing, indicating the breaking up of the loosely bound floc particles. When water was employed a

similar result was observed. It was considered of interest to determine the nature of the substances which were readily dispersed from the floc.

Returned sludge was washed successively with water and from each washing a 500 c.c. portion was taken for organic nitrogen and total solids determinations. Similar determinations were made on the original sludge. In Table I the results obtained with two sludges are given.

TABLE I.—*Character of the Dispersed Floc Obtained by Washing Activated Sludge With Water*

	Hillsdale				Morristown			
	Org. N	Vol. Matter		N in Vol. Matter	Org. N	Vol. Matter		N in Vol. Matter
	p.p.m.	p.p.m.	%	%	p.p.m.	p.p.m.	%	%
1st wash	3.6	55.4	42.9	6.5	5.5	48.4	49.5	11.4
2d wash	2.3	36.2	39.0	6.3	5.9	53.4	73.6	11.0
3d wash	1.9	36.8	40.9	5.1	6.2	46.6	79.2	13.3
Original sludge	1,240	14,100	79.2	8.8	411	3,910	81.7	10.5

The organic nitrogen in the volatile matter of floc particle dispersed by the washings is compared with that of the whole sludge particle. It can be seen that in the Hillsdale sludge the readily dispersed floc had a lower organic nitrogen content than the original sludge while with Morristown sludge the opposite was true. It is also interesting to note that the readily dispersed floc from Hillsdale had lower percentage of volatile matter than the original sludge. In the Morristown sludge this was the case with only the dispersate from the first wash. The percentage of volatile matter in the subsequent washings increased and approached that of the original sludge. The total amount of organic nitrogen dispersed by the three washings of Hillsdale and Morristown sludges was 7.8 and 17.6 p.p.m. respectively. The total amount of volatile matter dispersed was 128.4 and 148.4 p.p.m. for the two sludges.

EFFECT OF VARYING THE AMMONIA CONTENT OF THE SEWAGE AND RETURNED SLUDGE ON PURIFICATION

In the first paper of this series [3] results of unsuccessful attempts to show the adsorption of ammonia by activated sludge were reported. It was considered of interest to determine the effect on clarification of sewage by varying the ammonia content of the sludge. Similarly the effect on the clarification of sewage by activated sludge, by increasing the ammonia content of the sewage, was determined. Two types of sludges were used, one with poor clarifying power and another with good clarifying power. The NH_3–N content of the original sewage, treated sewage, and returned sludge and of the mixtures, as well as the turbidities of the supernatants after 6 hours aeration, are given in Table II. Increasing the NH_3–N content of the original sludge or the

sewage did not affect the clarification of any of the mixtures made with them, neither with the poor nor with the good clarifying sludge.

TABLE II.—*Effect of Treating Returned Sludge and Sewage With Dilute NH_4Cl Solution on Subsequent Clarification*

	Poor Clarifying Sludge		Good Clarifying Sludge	
	NH_3-N	Turbidity*	NH_3-N	Turbidity*
	P.p.m.	P.p.m.	P.p.m.	P.p.m.
Original sludge	1.8		0.85	
Treated sludge	60.0		45.0	
Original sewage	35		25	
Treated sewage	—		80	
R.S.+S.	25	80	20	less than 20
R.S. treated+S. not treated	35	75	25	" " 20
R.S. not treated+S. treated	80	80	60	" " 20
R.S. treated+S. treated	—	—	70	" " 20

R.S. = Returned Sludge.
S. = Sewage.
* Turbidity of supernatant after 6 hours aeration.

Effect of Treating Activated Sludge With Kaolin and Butyric Acid on Subsequent Clarification of Sewage

If clarification is due to adsorption, then treating a sludge with an inert material such as kaolin, prior to addition of sewage, should affect the clarifying power of the sludge. It would seem that satisfying the adsorptive capacity of sludge by kaolin should reduce the further adsorption of sewage colloidal matter. Accordingly returned sludge (20 per cent by volume) was aerated with a kaolin suspension (80 per cent) for one hour. It was settled, mixed with sewage (80 per cent) and aerated for 1 hour. The turbidity of the supernatant obtained was compared with the turbidity of a mixture of sludge and sewage without prior treatment with kaolin. The turbidity results are given below:

	Turbidities, p.p.m.		
	Sludge+Kaolin	Kaolin Treated Sludge+Sewage	Non-Treated Sludge+Sewage
Initial	115	150	150
After 1 hr.	70	85	85

A considerable amount of the kaolin was removed by the sludge but the inclusion of the kaolin in the sludge did not affect the subsequent clarification of the sewage.

In a similar way the effect of the treatment of sludge with butyric acid on subsequent clarification of sewage was determined. A portion of returned sludge was treated with 100 p.p.m. of butyric acid and

aerated for ½ hour. At the end of this period the treated and untreated sludges were centrifuged, the supernatant decanted and replaced with distilled water. To the sludges thus prepared sewage (80 per cent by volume) was added and aerated for a period of one hour. The turbidities of the supernatant liquors were as follows:

	Turbidities, p.p.m.	
	Control	Butyric Acid Treated Sludge
Initial	150	150
After 1 hr.	50	50

It is evident that the prior treatment of the sludge with butyric acid did not affect the clarification of the sewage. The pH value of the sludge was lowered as a result of butyric acid treatment from 7.3 to 6.7 but at the end of ½ hour preliminary aeration the pH had recovered its original value. Similar results were obtained with the titratable acidity before and after aeration of the butyric acid treated sludge.

Clarification of Sewage by Different Activated Sludges

The clarifying power of an activated sludge toward different sewages and the clarification of a given sewage by different activated sludges was determined, to ascertain whether there were inherent differences in the clarification of different sewages or whether the character of the activated sludge was of most importance. A study of the possible adaptation of the clarifying power of a sludge, for the particular sewage from which it was produced, was another phase of this problem. Sewage and returned sludge were obtained from three different activated sludge plants. The suspended solids concentrations of the two more dilute sludges were increased to the value of the more concentrated one by centrifuging. Equal volumes (20 per cent) of the three sludges were then mixed with the different sewages so that each sludge was mixed with each of the three sewages. The nine mixtures thus obtained were stirred in the stirring machine and the turbidities were determined on the supernatant after ½ hour settling. The turbidities of the original sewage diluted with water in the same proportions as in the sludge mixtures, were also determined. The differences were taken to represent the immediate clarifying action of the sludge. The results are given in Table III.

There was an appreciable reduction in turbidity immediately after mixing and settling, but if the turbidity of supernatant after immediate mixing and settling is taken as a basis of comparison, the mixtures made with the different sewages and sludges did not reveal any significant differences in the turbidity after 30 minutes of mixing. A different interpretation might be given when the original corrected turbidities of the sewage are considered.

TABLE III.—*Effect of Source of Sludge* [1] *and Sewage* [2] *on Clarification*

Sludge	Sewage	Turbidity		
		Original [3] Sewage	Immediately After Mixing and Settling	After 30 Minutes Stirring and Settling
		P.p.m.	P.p.m.	P.p.m.
Bernardsville	+Bernardsville	100	90	85
Bernardsville	+Morristown	185	105	90
Bernardsville	+Madison	140	95	90
Morristown	+Bernardsville	100	75	70
Morristown	+Morristown	185	85	85
Morristown	+Madison	140	75	70
Madison-Chatham	+Bernardsville	100	85	70
Madison-Chatham	+Morristown	185	100	90
Madison-Chatham	+Madison	140	85	70

[1] Suspended solids in original sludge: Bernardsville = 3,890 p.p.m., Morristown = 5,765, Madison-Chatham = 9,135 p.p.m.

[2] Suspended solids in original sewage: Bernardsville 140 p.p.m., Morristown 150, Madison-Chatham = 200 p.p.m.

[3] Diluted with 20 per cent water.

DISCUSSION

Air, Nitrogen and Stirring.—The results indicate that best clarification of sewage by activated sludge was obtained with air, next by stirring and finally by nitrogen. The results obtained with nitrogen gas are of interest because in two out of three experiments, nitrogen gas gave not only poorer results than air but the clarification became progressively poorer as agitation with nitrogen gas was continued. These sludges were obtained from Madison-Chatham. With one sludge an initial removal of turbidity took place with nitrogen gas, but as agitation with nitrogen gas was continued the turbidity of the supernatant increased. These results were obtained with sludge from Hillsdale. In the experiment dealing with the character of the floc separated from sludges by washing, it was shown that sludge from Hillsdale did not break apart by washing to as great an extent as the sludge from Morristown. It is therefore reasonable to attribute to this factor the differences observed in the behaviour of the two sludges in regard to the effect of nitrogen gas on the turbidity of the supernatant. Normally when air is passed through an activated sludge-sewage mixture the flocculating action predominates over deflocculation. With nitrogen gas the reverse is true. The extent of the deflocculating action varies with different sludges, dependent on the strength with which the floc particles are held together. The slight initial clarification obtained by agitating certain sludges with nitrogen gas might be explained on the basis of relatively low deflocculating action due to the strength with which sludge particles are held. Under these conditions a certain degree of turbidity removal might take place, because of the previously

aerated condition of the sludge. This clarifying power, however, would soon be lost under the influence of sustained agitation with nitrogen gas and constant dosage with sewage.

Buswell [2] states that air diffused through mixed liquor in the activated sludge process serves three purposes: (1) maintains the sludge in suspension, (2) maintains aerobiosis, (3) stirs the mixture, bringing particles together. Assuming that these are the important functions of air, agitation with nitrogen gas maintained the sludge in suspension and brought the particles together. It would therefore seem that maintenance of aerobic condition is essential, even during the clarification stage. It would further follow that if the sludge serves as an adsorbing surface during the clarification stage, it does so only in the presence of air. Ordinary adsorption reactions are not influenced by air. Adequately reaerated returned sludge, in which the sewage impurities have been more or less completely eliminated and adsorptive surfaces reestablished, should yield some initial physical adsorption irrespective of the presence or absence of air during that stage. It is true that this action would be stopped in the absence of air once sufficient sewage colloids have been adsorbed by the floc. It is further of interest to note in this connection that by stirring in an open vessel clarification was not completely inhibited. The maintenance of sludge in suspension and adequate contact between particles were furnished by the paddles and sufficient oxygen was supplied through the surface to allow a limited amount of clarification to take place.

Wilson and Calvert [7] questioned the possibility of obtaining effective aeration by the use of nitrogen gas.

Baker [1] determined the effect of separately bubbling CO_2, air and oxygen through sewage. He found that there was a decrease in turbidity on bubbling CO_2 for one hour but that the turbidity thereafter increased until it far surpassed the turbidity of the original sewage. With air and oxygen the normal reductions in turbidity were obtained. Baker attributed the initial decrease in turbidity with CO_2 treatment to the oxygen already present in sewage.

Williams [5] discusses the experiments conducted at the University College, London, on the coagulation of sewage colloids by bubbles of different gas. The results with air, oxygen, hydrogen and nitrogen indicated that the extent and rate of the coagulation observed was independent of the gas employed during the six hours of bubbling. But over a period of 24 hours the order of efficiency of the coagulation of dispersate was oxygen, air, hydrogen and nitrogen. While these results would indicate the importance of physical action in the coagulation effect of gas bubbles, they would not rule out the possibility of biological action, as was admitted by the author. It is conceivable that different types of biological action take place under aerobic and anaerobic conditions, giving the same end result. Enzymic action and bacterial synthesis, resulting in the coagulation of the dispersate, are not ruled out. The higher coagulation values obtained with the different gases at 80° C., in comparison with 25° and 37° C., are difficult to explain on

this basis. The temperature difference is great and beyond the practical working conditions, hence it is reasonable to assume that agents bringing about the coagulation at these two ranges are not the same. Furthermore, little if any coagulation was obtained at 0° and 10° C. by any of the gases.

In a second paper Williams and Murray [6] reported that sterilization of sewage by potassium cyanide, mercuric iodide and ultraviolet rays resulted in a greatly reduced coagulation brought about by gas bubbles. They stated that "though this might be due to the inhibition of bacterial and enzyme activity, an alternative explanation is that some type of surface poisoning is produced which prevents coagulation." They consider the second explanation as the most likely. Bacteria were not entirely eliminated by any of the treatments although they were greatly reduced.

Agitation of sewage with glass paddles, practically out of contact with the atmosphere, was not so effective in bringing about coagulation as bubbling oxygen gas.[5] Although strict comparisons are not possible our results indicate a similar conclusion. Working with activated sludge and sewage mixtures, instead of plain sewage, introduces other factors besides the coagulating effect, such as the deflocculation phenomenon of the sludge itself.

A clue to the effect of stirring on coagulation of sewage might be obtained from its influence on bacterial numbers. Accordingly, two experiments were run. In the first experiment both the stirred and unstirred samples were open to the atmosphere. In the second experiment the effect of stirring in a closed system was compared with the effect of stirring in an open system. The stirring in all cases was with horizontal paddles at a speed of 20 r.p.m. The stirring in the closed system was accomplished with only a very small surface of the sewage present in the collar for the bearing of the stirrer in contact with the atmosphere. The results from both series (Table IV) indicated that

TABLE IV.—*Effect of Stirring Sewage on Bacterial Numbers*

		(Plate counts in millions per c.c.) Hours Stirring			
		0	4	24	48
Exp. 1.	Stirred, open to atmosphere	8.2	7.4	21.2	—
	Not stirred, open to atmosphere	8.2	8.0	4.3	—
Exp. 2.	Stirred, open to atmosphere	31.0	—	99	44
	Not stirred, open to atmosphere	31.0	—	15.7	6.4
	Stirred in closed system	31.0	—	22.0	21.0
	Not stirred in closed system	31.0	—	9.1	2.3

when sewage was stirred in an open system for a period of 24 hours, there was an increase over the original numbers of bacteria. In the unstirred sewage during the same period of time, the bacterial numbers decreased. Stirring the sewage in a closed system did not result in an

increase of bacterial numbers similar to the increase in the open system, but the great drop in bacterial numbers in the unstirred sewage was prevented.

Thus both stirring and the presence of air are important factors which influence the bacterial numbers. That the increases in bacteria obtained by stirring are not primarily due to the effect of stirring on the dispersion of the original bacterial aggregates, is indicated by the fact that in the closed system such stirring did not result in an actual increase. It would seem that the observed phenomenon was the result of the effect on bacterial multiplication. Greater bacterial multiplication and activity should be reflected in the clarification and coagulation of the sewage. These moderate increases in bacterial numbers may be a part of the major effect on special types of bacteria, the numbers of which might be entirely missed in the routine agar plate growths. These organisms are apparently stimulated by the small amounts of air that diffuse into the sewage when the surface is kept in contact with the atmosphere. These organisms may bring about profound changes in the sewage itself by their hydrolytic and synthetic activities, resulting in clarification and coagulation.

That coagulation of sewage dispersates is hastened by keeping the sewage open to the atmosphere, without stirring or artificially bubbling any gas, is shown in Table V. Two portions of cotton-filtered

TABLE V.—*Purification of Sewage in Open and Closed Vessel*

Hours	Open Vessel				Closed Vessel			
	4	24	48	72	4	24	48	72
Whole sewage, B.O.D., p.p.m.	500	425	420	310	500	425	480	400
Supernatant after settling, B.O.D., p.p.m.	250	170	140	65	285	215	195	198
Seitz filtrate, B.O.D., p.p.m.	135	100	63	47	135	130	130	130
Turbidity, p.p.m.	160	110	65	50	190	145	95	105

sewage were kept quiescent at 24° C.; in one portion the air was excluded and the other remained open to the atmosphere to a depth of 4 to 5 inches. The results indicate that clarification and flocculation were increased considerably in the sewage kept open to the atmosphere, as measured by the B.O.D. values of the settled, unsettled and Seitz filtered sewages, as well as the turbidity results. The sewage, as is indicated by the B.O.D. values, was very strong and became septic rapidly in the open vessel. The only source of oxygen was from the surface by natural diffusion into a liquid layer of 4 to 5 in. deep. Furthermore, the indicated purification was effected without the introduction of biologically active slime. The reductions in B.O.D. are revealed both in the colloidal and soluble portions. The sewage in the open vessel during 72 hours showed a loss of 190 p.p.m. of B.O.D. The sewage after sedimentation showed a loss of 185 p.p.m. of B.O.D. Not all of this loss was due to flocculation since the Seitz filtrate, which in-

cludes to a great extent the soluble fraction, revealed a loss of 88 p.p.m. of B.O.D. Most of the loss in the Seitz filtrate fraction can be considered due to biological stabilization and oxidation. In the closed vessel this portion was subjected to a loss of only 5 p.p.m.

Effect of Treating Activated Sludge With Sewage and Water on its Clarifying Power and the Nature of the Floc Dispersed.—The two experiments on treating the sludge with various volumes of sewage and water gave contrary results. With Hillsdale sludge treated with 30 volumes of sewage, the clarifying power was only slightly affected, while the clarification with Morristown sludge treated with 66 volumes of sewage was definitely inhibited. A part of the difference observed might be attributed to the differences in the volumes employed and another part to the differences in the nature of the sludges. It has been shown by Wooldridge and Standfast [8] that treating activated sludge with 120 volumes of sewage retarded the oxidizing power of the treated sludge for sewage. A sludge saturated in this way required 5 hours of aeration before its activity to oxidize more sewage became approximately equal to that of the original sludge. It would seem that the clarifying power also is adversely affected by supersaturation with sewage colloids. A reaeration period of 24 hours was not sufficient to overcome this inhibitory effect on clarification.

That sludges may have different physical powers of adhesion is indicated by the effect of washing of the Hillsdale and Morristown sludges, with water, on the amount and character of the dispersed floc. The three washings dispersed more volatile matter and organic nitrogen with Morristown sludge than with Hillsdale. The percentage of volatile matter in the dispersed floc was higher with Morristown sludge than with Hillsdale. The Hillsdale sludge was more highly stabilized than that from Morristown. It is interesting to note that the percentage of volatile matter in the dispersed floc from Morristown was low (49.5 per cent) in the first wash but increased in the second and third washes (73.6 and 79.2 per cent). This would indicate that the more highly stabilized material was dispersed more readily. The percentage of nitrogen in the volatile matter of the dispersed floc was also higher in the Morristown sludge than in the Hillsdale sludge.

The Effect of Pretreating the Sludge with NH_4Cl, Kaolin and Butyric Acid on Its Clarifying Power.—The results presented in connection with the pretreatment of activated sludge with NH_4Cl solution indicate that the subsequent clarifying power of the sludge towards sewage was not affected. In a similar way increasing the ammonia content of the sewage did not affect the ability of the sludge to clarify it. The original ammonia content of either the sewage or the sludge was considerably increased by artificial treatment with NH_4Cl solution (up to 80 p.p.m.) without resulting in a curtailment of the clarifying efficiency of the sludge for sewage. Thus, variations in the ammonia content of the sewage or the sludge can be eliminated as factors in the clarification efficiency. It can further be stated that the adsorptive

power of the sludge is not adversely affected by a high ammonia content in the sludge.

In a similar way pretreating the sludge with kaolin and butyric acid did not reveal any effect on the clarifying power of the sludge. That the kaolin was actually transferred to the floc is indicated by the reduction of the turbidity of the supernatant. The transference of kaolin to the floc did not over-burden the oxidizing power of the sludge, since it did not add any organic load. Therefore, reaeration should not be necessary to rehabilitate the clarifying power of the kaolin-treated sludge, as in the case of the sludges saturated with sewage colloids. If the kaolin was removed by adsorption, the power of kaolin-saturated sludge to remove sewage colloids should be reduced. Yet when a kaolin-treated sludge was aerated with sewage, no deleterious effect was observed on clarification. It would seem logical to conclude, therefore, that either kaolin was not removed by adsorption or that the removal of kaolin and the removal of sewage colloids by activated sludge are the result of two different phenomena.

That a part of the kaolin removal is the result of ion exchange phenomenon is illustrated in the following experiment. Kaolin was mixed with sludge and with the supernatant liquor of the sludge. The two mixtures were stirred in a stirring machine for one hour. Initially, and at the end of 1 hour, turbidity and the total solids of the supernatant after centrifuging were determined. The results given in Table VI indicate that even with sludge liquor, removal of kaolin takes place,

TABLE VI.—*Comparison of the Removal of Kaolin by Activated Sludge and Activated Sludge Supernatant Liquor*

	A Sludge + Kaolin	*B* Liquor + Kaolin
Turbidity initial, p.p.m.	75	115
Turbidity after 1 hour mixing, p.p.m.	25	70
Total solids on supernatant initial, p.p.m.	420	465
Total solids on supernatant after 1 hr. mixing, p.p.m.	340	400
Ash in total solids on supernatant initial, p.p.m.	265	320
Ash in total solids on supernatant after 1 hour mixing, p.p.m.	195	270

(*A*) Activated sludge 900 cc. kaolin 100 cc.
(*B*) Supernatant liquor of activated sludge 900 cc. kaolin 100 cc.

as is indicated by the total solids and turbidity figures. The removal of kaolin by the liquor is not so high as by the sludge itself. Since the addition of kaolin and the stirring might cause some deflocculation of sludge particles, the ash figures of the supernatant liquid are probably more reliable in evaluating the removal of kaolin.

A similar experiment was conducted with sewage. Sewage was aerated with activated sludge and its liquor. For comparison another portion of sewage was aerated with a corresponding volume of water. The removals of turbidity and B.O.D. from the supernatant liquor are given in Table VII. It is evident that the sludge liquor did not bring

TABLE VII.—*Comparison of Clarification of Sewage by the Liquid and Sludge Portions*

	Turbidity, p.p.m. Hours Aeration			B.O.D., p.p.m. Hours Aeration		
	0	1	2	0	1	2
1. Sewage [1]	140	150	135	100	85	90
2. Sewage + sludge liquor [2]	140	150	140	105	95	80
3. Sewage + activated sludge [3]	150	85	65	110	40	50

[1] Sewage + 20 per cent water.
[2] Sewage + 20 per cent centrifuged and filtered activated sludge liquor.
[3] Sewage + 20 per cent activated sludge.

about any removal of turbidity and only a slight removal of B.O.D. in 2 hours. Thus sludge liquor was not as effective in removing sewage colloids as it was in removing kaolin.

The picture is not so clear-cut with the butyric acid treatment of sludge as with kaolin, since butyric acid is subject to bacterial decomposition. With only half an hour preaeration of butyric acid with the sludge in order to minimize the bacterial action, the pH value changed from 6.7 to 7.3 and subsequent clarification of the sewage was not affected.

Effect of the Source of Sludge and Sewage on Clarification.—Treatment of sewage obtained from different localities by the respective sludge from the same localities, and by sludge from entirely different localities, did not manifest any effect on clarification. There were differences in the turbidities and suspended solids content of the different sewages but by mixing them with sludges obtained from the same plant no better final results were obtained than by mixing them with entirely different sludges. It would seem, therefore, within the limitation of the experimental method employed, outside of the strength of sewage, there are no particular peculiarities regarding normal domestic sewage from the standpoint of clarification. Nor is there a special adaptation created by the production of a sludge from a particular sewage.

GENERAL DISCUSSION

In the evaluation of the clarifying power of activated sludge, time is an important factor in distinguishing it from oxidation. When does clarification end and oxidation start? It is assumed that clarification is the more rapid initial phenomenon. It has been shown by Theriault and McNamee,[4] in a study of the adsorption of ammonia by activated sludge, that an equilibrium is reached in 20 to 30 minutes. Hence, most of our experiments on clarification were conducted for a period of one hour. Evidence has been produced to show that the turbidities obtained after mixing sewage with activated sludge and settling immediately thereafter, are sometimes considerably lower than the expected turbidities, on the basis of dilution of sewage by a similar vol-

ume of distilled water. It should be borne in mind that even here the time of contact of sludge with sewage is considerably more than instantaneous. The sludge remains in suspension for varying periods. In spite of the fact that biological action is not precluded during this period, it might be admitted that this observed phenomenon is to a great extent what might strictly be called non-biological clarification. Thereafter mixing the sludge by paddles (for ½ to 1 hour) with sewage brings about a limited removal of turbidity. By passing air through the mixture the removal of turbidity is hastened.

The investigations thus far presented indicate definitely the complexity of the clarification phenomenon and the great number of factors involved. It has been shown that an inert material like kaolin is rapidly removed by activated sludge. That a considerable part of this removal can be brought about by the liquor of activated sludge is also shown. This might be explained on the basis of an ion-exchange phenomenon. The repeated observations on the immediate removal of kaolin by activated sludge might be attributed to this ion exchange factor which can also be brought about by the liquor itself. However, in the purification of sewage the ion exchange exerts only a moderate influence, as is indicated by the experiment on the purification of sewage by sludge liquor. The indirect evidence so far produced emphasizes that sludge has other mechanisms. That sludge fully saturated with kaolin keeps on clarifying sewage is one of the evidences pointing in this direction. On the other hand clarification of sewage cannot take place by a sludge which has been fully saturated by sewage materials.

The biological factors in the so-called clarification stage have been entirely overlooked. Evidence will be produced in subsequent papers that they are operative in the clarification stage. The rapid removal of organic materials such as sugars, butyric acid, casein, peptone and of sewage organic materials need not necessarily be interpreted as a physical phenomenon as long as biological factors are not entirely excluded. That the biological factors cannot be entirely disregarded is shown in a general way by the increase of bacterial numbers of sewage by stirring and the accompanying higher clarification. The higher clarification obtained in the presence of air, both in sewage and activated sludge mixtures, points also in the same direction.

Another complicating factor is the relative importance of flocculation and deflocculation. It has been pointed out that under certain circumstances and with certain sludges the deflocculating action may predominate.

Summary

In the clarification of sewage by activated sludge, best results were obtained by air, followed by stirring, and poorest results with nitrogen. Agitation with nitrogen gas with some sludges gave a slight initial clarification, with other sludges the clarification was completely obstructed and the supernatant became progressively worse with increasing periods of agitation.

The relative effects of aeration and agitation by mechanical mixing and nitrogen on the adsorption and biological activities are discussed. Results are given to show that mechanical mixing of sewage, which is known to enhance clarification, also resulted in higher bacterial numbers.

Saturation of activated sludge with sewage colloids resulted in impaired clarification, while saturation of sludge with kaolin did not affect its clarifying power for sewage. Similarly, butyric acid treatment of the sludge did not affect its clarifying power. Increasing the ammonia content of the sludge and/or the sewage did not affect the clarifying power of the sludge for sewage.

It is concluded, therefore, that clarification is a complex phenomenon brought about by a number of factors. The removal of inorganic colloidal material such as kaolin may well be the result of adsorption or ion exchange while in the removal of sewage organic impurities, biological factors must be considered.

Sludge readily deflocculates under the influence of excessive agitation, or by agitation with nitrogen gas, and by washing. The character of the dispersed floc (by washing) is much different than the whole sludge floc itself. These variations are revealed by differences of the volatile matter and nitrogen content of the dispersed material. By successive washings the character of the dispersed floc is changed. The volatile matter content of the dispersed floc in a well oxidized sludge is lower than the volatile matter content of the whole sludge itself. In a poorly oxidized sludge the volatile matter of the dispersed floc, after the first washing, is nearly as high as the volatile matter content of the whole sludge.

References

1. G. C. Baker, "Some Factors in the Purification of Sewage by Activated Sludge Process," Univ. Illinois, *Bull. Water Survey Series*, No. 14.
2. A. M. Buswell, "Importance of Oxygen and Stirring for Activated Sludge Growth," *Eng. News Rec.*, 1923, p. 835.
3. H. Heukelekian, "Studies on the Clarification Stage of the Activated Sludge Process," *This Journal*, **8**, 873 (1936).
4. E. J. Theriault and P. D. McNamee, "Adsorption by Activated Sludge," *Ind. Eng. Chem.*, **28**, 79 (1936).
5. E. Williams, "The Nature and Amount of the Colloids Present in Sewage. Part VII. The Effect of Bubbles of Gas and Agitation on Sewage Liquor," *Soc. Chem. Ind.*, **54**, 355–61T (1935).
6. E. Williams and E. Murray, "Studies on the Nature and Amount of the Colloids Present in Sewage. Part VIII. The Effect of Bubbles of Gas on Sterilized Sewage Samples," *Soc. Chem. Ind.*, **55**, 281T (1936).
7. H. M. Wilson and H. T. Calvert, "Activated Sludge Process," by A. J. Martin, p. 145.
8. W. R. Wooldridge and A. F. B. Standfast, "Certain Factors That Influence the Rate of Activated Sludge and Sewage Oxidation," *Biochem Jr.*, **30**, 156–162 (1936).

Plant Operation

NORTH OUTFALL SEWER INSPECTION, CITY OF LOS ANGELES *

By Reuben F. Brown

Asst. Supt. of Sewer Maintenance, Los Angeles, Calif.

The interior inspection of the north outfall sewer of the City of Los Angeles, extending from Centinela Avenue to the screening plant at Hyperion, was made and completed during the month of July, 1936. The cross section of this portion is semi-elliptical of 1:3:5 un-reinforced concrete with 15 in. of crown thickness and 36 in. thickness at the footings. The sewer is 10½ ft. high and 12 ft. 3 in. wide. Above the spring line the interior was lined with vitrified clay lining blocks 9 in. wide by 18 in. long and ¾ in. thick, with Portland cement mortar joints.

This sewer was completed and placed in use 12 years ago. In March, 1934, a reinforced concrete blanket was constructed over a leak discovered during the heavy rains of that year. Investigation had shown from time to time that storm water gained access to the separate sewerage system and caused the outfall to flow under pressure, with the result that surface seepage appeared at points where the earth cover was shallow. Test pits showed that longitudinal cracks had developed due to eccentric side hill loading. These were repaired by a 12 in. reinforced concrete blanket.

These conditions suggested the necessity of inspecting all parts of the outfall sewer from the interior to see if other portions had been damaged by earthquake, by the effects of gases or from other causes.

History of the Inspection

In April, 1934, preliminary office work was started to determine the interior condition of this sewer.

In August, 1935, the Council appropriated funds for material and equipment whereby a safe inspection could be made. Because of the danger of inspection, the only observation of the interior since its construction in 1922 was from a few manholes.

On May 13, 1936, the City Council authorized the purchase of $25,000 special accident and health insurance for the inspector from Lloyds of London, as other companies contacted had declined the risk. It was at this time that the sewer maintenance division was instructed to make the inspection, and to become familiar with details and tests of equipment.

* Presented at the Ninth Annual Spring Conference of the California Sewage Works Association, Stockton, April 23 and 24, 1937.

On the morning of July 4, 1936, at 6 A.M., the first official inspection was started with the accompanying international publicity and widespread public interest in municipal sanitation and sewer maintenance. It was the first time a sewer of this type and size had such an extensive inspection while in use and subject to gas and other hazards. It was the first time the method of communication adopted was used in the inspection of sewers. It was the first time that verbal and pictorial records were made at the same time in an inspection of this kind and under these conditions.

Length of Outfall Sewer

The outfall sewer extends from the upper part of the San Fernando Valley to the sea, its total length of fifty miles making it one of the longest outfall sewers in the world. It takes the sewage from Burbank, Glendale, Eagle Rock, Highland Park, El Sereno, Boyle Heights, the downtown and southern parts of Los Angeles, Vernon, Venice, Santa Monica, Hollywood, Ocean Park, Beverly Hills, Sawtelle and several County Sanitation Districts. It has an average flow of 114 million gallons per day.

The detailed underground inspection covered the last six miles, as this portion carries the full load of the entire city except the Harbor district.

Cooperation of Divisions

Because of preliminary findings from exterior examinations and in conformity with the planned maintenance program of the Bureau of Engineering, Mr. Lloyd Aldrich, City Engineer, authorized the inspection of this gas-filled sewer line.

Nearly every division of the Engineering Bureau and other bureaus under the Board of Public Works cooperated in the preparation, preliminary testing or actual performance of the work. Those directly responsible for a true and accurate report of the interior conditions and safety of the men were Mr. H. G. Smith, Engineer of Sewer Design, Mr. H. P. Cortelyou, Engineer of Disposal of Waste, and Mr. F. A. Batty, Superintendent of Sewers. The inspections were made by the author, who is Assistant Superintendent of Sewer Maintenance.

Preliminary Tests

Making this inspection required careful preliminary study of the methods and equipment to be used. Every piece of equipment used was tested in advance as to actual performance. Gas mask instruction was given and short tests made in gas filled lines. Communication systems were tried out and tested for use. Two thousand feet of high-strength ¼ in. aircraft cable, supposedly to be used to hold the boat back, was tested for static friction and sliding friction and developed at 2,000 feet 80 lb. static and 70 lb. sliding friction on pavement. The boat under test of 800 lb. load had about 4 in. freeboard; with 340 lb. load

it had 8 in. freeboard and was very stable. When filled with water it had sufficient buoyancy because of air chambers to support the inspector at the surface. A "Mine Safety Appliance" oxygen outfit used by the inspector was tested under water with little inconvenience to him in swimming. The drag board used to develop power to pull the boat and cable was tested inside the breakwater at Santa Monica. Speeds were determined by current meter and the drag in pounds measured by a large spring balance. These tests were made in the early morning in both quiet and rough water and developed a power pull in pounds at a velocity of 2.70 ft. per sec. of 80 lb.; at 2.80 ft. per sec. of 80 to 100 lb.; at 2.90 to 3.40 ft. per sec. of 150 to 160 lb.; and at 4.20 ft. per sec. developed a 200 lb. pull. It also showed that when heavy pull or drag occurred, the board would jump at 150 lb. pull. This same condition occurred during actual inspection and caused the abandonment of the cable provided to hold and control the progress of the boat. Sanitary rules were enforced among the crew for handling of any equipment used in the sewer.

Procedure—Methods and Equipment

There was constructed a specially designed boat 9 ft. long with a 32 in. beam equipped with removable air tanks or sponsons, which were attached to the side after the boat had been lowered into the sewer, to give it additional stability. The boat's accessories included two steering rudders, a drag board 3 ft. wide to develop power or pull, two anchors and a boat hook.

Two steel cages suspended with platforms slightly above the sewage level were used for loading, starting and landing the boat, and also as look-out stations for signals. Three additional wooden platforms were placed in use after inspection started to avoid delay in moving equipment. Twenty-six inspection openings from 500 to 2,000 ft. apart were cut in the sewer, measuring about 3 ft. 5 in. by 4 ft., and the upper portion of one existing manhole was removed. The centers of these openings were cut to one side of the center line, in order that the cable frame, when placed beside the platform, would be on the center line of the sewer. The overburden on the sewer was excavated to provide a working space 12 ft. square around the openings. Where roads, either private or public, were not available adjacent to the sewer, a roadway wide enough to drag a stone boat by a tractor was cut out of the side of the hill. The air suction and blower fans with their gas engines, the boat cable winch and light cable reel, the platform frames, water and antiseptic soap barrels, and all miscellaneous equipment were moved from hole to hole on stone boats by tractor.

The blower and suction fans were set up near the section to be inspected and operated at least an hour before and during the period of inspection, which was made at low flow between 5 A.M. and 9:30 A.M.

Horizontal curves in the sewer made it impossible to see from one opening to the next opening in practically all cases. Therefore a scow with approximately the same draft as the inspection boat was floated

through the sewer before each day's work was started, to insure that there was no obstruction in the line.

Through the opening at the upper end of the section of sewer which was to be inspected, the boat, with all equipment removed including the sponsons, was lowered into the sewer, using a chain block supported by a pipe tripod. Platform frames were then lowered and blocked up level at this opening and at the openings immediately downstream. The portable light cable reel having been hauled to the upper opening, the cable end was attached to the boat, the generator started and the flood lights turned on. The boat was then equipped with its accessories together with induction telephone transmitter and receiver. Bottles for samples of air, sewage, algae, cement, etc., for testing by

FIG. 1.—The start, July 4, 1936.

the laboratory, were placed in the boat. When working, either in the boat or on the platforms, acid-type or all purpose canister masks were worn by the men. Field tests for explosive gas, carbon monoxide, and hydrogen sulphide were made before entering the sewer and during the period of inspection work.

The preliminary work of moving platforms and equipment into place having been done, either the previous day or day of inspection, the oxygen helmet was donned and the boat entered when the depth of sewage was less than 42 inches. Communication was established with the ground crew, the boat cast loose and the inspection was under way (Fig. 1). As the boat floated downstream, the earth-induction telephone receiver on the surface was carried forward and, by the varying strength of signals, the boat's position could be determined within a

few feet. Markers placed on the surface showed the interior condition, as reported from the boat.

This report was taken down in shorthand notes at the time of inspection. These notes were typed in the afternoon and checked for errors before starting the next day.

The boat could be stopped for detailed examination or for pictures by dropping the anchors, and its lateral position changed by use of the rudders, drag board or boat hook. When the alignment of the sewer was quite straight, the boat and drag board had power enough to drag about 1,100 feet of electric cable but where fairly sharp curves were encountered this distance became less. It was then necessary to disconnect the electric cable and drift, using only storage battery lights, down to the next opening where men on the platform caught the boat and made it fast.

Illumination was obtained by using two photo flood lights in explosion-proof reflectors, the current being supplied through waterproof cable mounted on a portable reel from a portable generator. Over nine hundred pictures were taken with these lights and the verbal descriptions and statements were supplemented by photographs, making a complete pictorial report of conditions found. The camera used was a Leica miniature, equipped with a very fast F 1.9 lens with exposures of 1/30 and 1/40 of a second with the shutter wide open.

Gas Conditions Dangerous

Tests of samples of the sewer atmosphere showed the presence of strong hydrogen sulphide gases, gasoline vapor, ammonia, oxygen, carbon dioxide, carbon monoxide, methane and other gases, some of which were combustible or poisonous. This sewer had always been sealed as tightly as possible to prevent escape of objectionable sewer gases. Trapping of sewer gases within sewers results in more danger than protection and its undesirability has been demonstrated by experience and research. To prevent creation of pressures above and below atmospheric, to prevent the concentration of odors, and the accumulation of dangerous explosive or corrosive gases, ventilation is desirable and necessary. Ventilation was provided during inspection to overcome the gas conditions encountered. One air blower and one air suction fan, mounted on skids and moved as necessary, were used to increase air circulation. Also as inspection progressed, each opening was left open and protected by wire coverings to allow natural ventilation.

Analyses made by the Bureau of Standards of the Department of Public Works and tests made in the field showed that oxygen (O_2) increased from 11 to 21 per cent as a result of ventilation. It was found possible to change low oxygen in 1,000 ft. sections to normal concentrations by proper use of fans. Before inspection was completed the whole line showed 20 to 21 per cent oxygen. Hydrogen sulphide (H_2S) changed from 20 p.p.m. to a trace. Explosive gas, tested with a UCC Indicator, changed from 5 point indication to zero, and was at zero when inspection was made. The 5-day B.O.D. tested from 357 p.p.m. to

490 p.p.m. Chlorides tested from 190 p.p.m. to 584 p.p.m. The pH value in sewage samples ran from 6.3 to 7.5 and on samples of interior wall deposits ranged from 3.8 to 8.6. B. Coli varied from 30,000 to 750,000 per cc. Analyses were made of all air samples, sewage samples and interior deposit samples as inspection progressed and this information is tabulated in the complete report.

General Condition of Sewer

Except near the outlet at Hyperion, the interior of the sewer when first opened was damp and there was a heavy yellow deposit on the sidewalls (Fig. 2). This yellow substance when analyzed was found to be

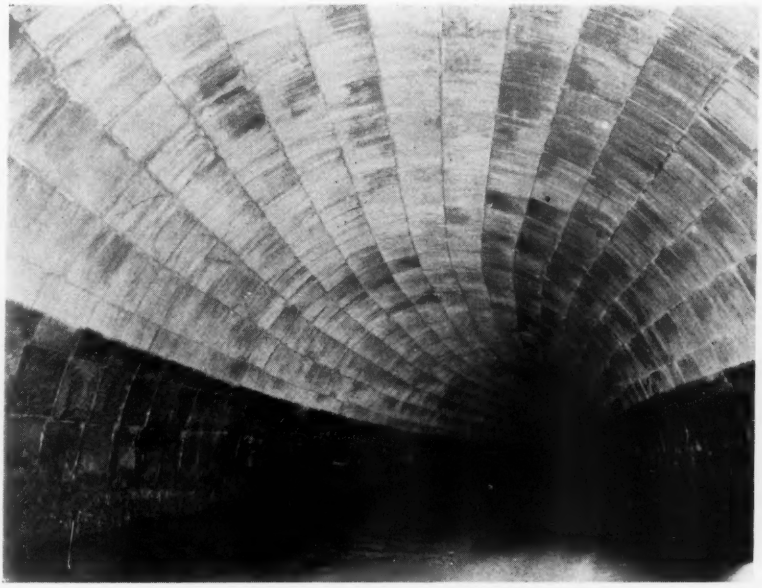


Fig. 2.—Considered in good condition. Note yellow growth on tile surface. Dark edge is water line.

an alkaline substance containing sulphur trioxide, metallic oxides, and calcium oxide; sulphur trioxide being formed by the oxidation of sulphur dioxide in the presence of ferric oxide and other catalysts.

From the uppermost hole, which was Hole 1, to Hole 13, the general condition was the worst encountered. There were many tile off, in many cases the tile being gone from large areas. There were also heavy spalling, soft joints and several transverse cracks (Fig. 3). From Hole 13 to Hole 20 the general condition was considered fair, although there were a number of places where tile was off; the cement joints were generally soft and there were several transverse cracks and a great deal of spalling. Between Hole 18 and Hole 19, however, there was found a large longitudinal crack on the south side about 480 ft. long, 3 in. to 5 in. wide and 10 in. deep. This crack was adjacent to the oil

wells located near the sewer right of way. This very dangerous condition required extra investigation and repairs will be made in the near future.

From Hole 20 to the outlet at Hyperion the condition of the sewer was better and as good as can be expected. The cement joints between the tile in the arch were found firm and appeared hard. On the sidewalls, however, the joints were softer. There was some spalling and a few tile were off.

Results of Inspection

As a result of this inspection and the tests made, together with a study of the photographic record, City Engineer Lloyd Aldrich in his official report submitted to the Board of Public Works December 2, 1936, summed up the following conclusions and recommendations:

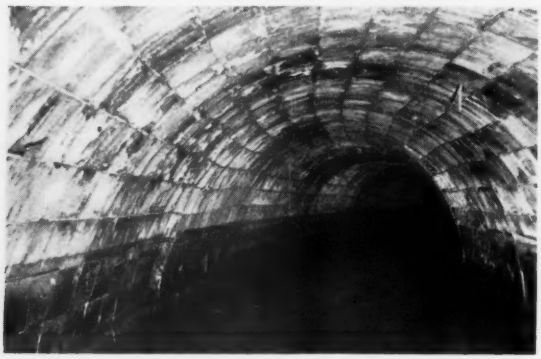


Fig. 3.—Tile off—Growth at base of tile. Heavy yellow growth on tile surface. Spalling. Tile pushed out.

Conclusions

"The disintegration of the north outfall sewer is occurring because of the action of the sulphuric acid on the Portland cement mortar joints between the clay tile lining blocks in the sewer, the sulphuric acid being formed by the oxidation of hydrogen sulphide gas in the presence of water. As the acid acts upon the mortar, the cement is softened and reduced to gypsum, which has a much larger volume than the cement. This increase in volume of the joint exerts a lateral pressure upon the edges of the tile. As the action of the acid penetrates the joint to the back of the tile, the swelling of the mortar cracks off a wedge-shaped piece of tile, referred to herein as spalling. This action progresses until the tile has been completely spalled off and the acid attacks the exposed concrete surfaces (Fig. 4).

It, therefore, appears that whole tiles have not fallen off, but have been broken off in pieces. This conclusion is confirmed by the fact that tile lugs are still embedded in many places in the exposed concrete where the tile lining is entirely gone; and where a tile has spalled, the remaining portion is not loose but sounds solid when tapped.

The cement joints between the tiles on the sidewalls, which are alternately submerged and exposed each day, are generally attacked first and as the disintegration progresses, the top of the sewer, which is seldom submerged, is affected.

Due to the fact that the grade of the sewer is uniform between the points of intersection of the horizontal curves, the grade along the center line of the sewer is materially increased in the horizontal curves of large central angle. At the ends of these horizontal curves where the steeper grade in the curve intersects the flatter grade of the tangent, the sewage flow is turbulent and there is invariably an indication of deterioration also occurring at the siphon inlet and outlet where there is considerable turbulence.

FIG. 4.—Disintegration. Tile pushed off. Gone. Rock exposed. Good picture of rock showing and cement around rock gone.

The inspection showed a wide variation of conditions of the sewer, the conditions changing materially within a very short distance. The rate of disintegration or relative rates of the various stages of disintegration are unknown."

RECOMMENDATIONS

"1. That shafts be sunk for an exterior inspection of the sewer in the vicinity of the oil wells, between Gulana Ave. and Hulbert Ave., where a major longitudinal crack is known to exist, and that plans be prepared for the repair of this section estimated to be 480 feet long.

The condition of the sewer in this location is dangerous and a break in this line would undoubtedly result in damage suits being filed against the city of Los Angeles.

2. That studies be made in order that recommendations may be presented for reducing to a minimum the action of the sewer gases upon the interior of the sewer, thereby prolonging the useful life of this expensive outfall before its condition becomes dangerous.

In addition to the Los Angeles sewage, which flows through this outfall, sewage from 16 outside cities and districts, under contract with the city of Los Angeles, flows through this outfall, Los Angeles agreeing in these contracts to maintain and keep in good condition and repair the outfall sewer.

3. That certain of the existing brick manholes be reconstructed in whole or in part so that they will be safe."

Interesting Experiences

There were interesting experiences, and valuable information was secured by the individuals connected with this inspection. Any one connected with maintenance and operation of sewage lines and plants will realize that it was a thrill to cut loose from the cable for the first time with no chance of being pulled back to the starting point. To have all the lights go off, to know your oxygen supply was low, to stand up and move around through necessity of cutting loose from the cable which was the only means of being pulled back to the landing platform instead of traveling down the sewer, gave a thrill to all persons connected with the work. To change gas masks while making inspection in the middle of a section and then to try to hold your breath while making the change, is really some experience. There was not a dull day, you can rest assured.

Our Los Angeles experience has demonstrated that with proper care and preparation, interior inspection of major outfalls can be made, that are of very real value to the science of sanitary engineering.

SYMPOSIUM ON MECHANICAL EQUIPMENT *

PUMPS, BEARINGS, CLARIFIERS AND PLANT LAYOUT

By Carl F. Tennant

Chief Operator, Joint Disposal Plant, Los Angeles County Sanitation Districts

Criticism has been solicited from operators. Therefore, I propose to treat the subject of mechanical equipment and plant design candidly and without reserve. The shortcomings of sewage plant design and mechanical equipment will here be presented from the operator's viewpoint in the hope that through a mutual comprehension of the problems that harass the operator, better equipment and improved design will result. If this is accomplished in some small way, this effort will be well repaid.

Sludge Pumps.—Let us first consider sludge pumps. Raw sludge is difficult material to handle with any pump. If the characteristics of sludge are considered it is apparent that some of the equipment for pumping sludge now on the market is obviously unsuitable for this purpose. Sludge is fibrous material containing small sticks, bones, sand, seeds, rags and finer particles mixed with varying amounts of water. It should therefore be apparent that almost any valve arrangement in a sludge pump will soon foul and give much trouble.

Some piston pumps widely used in sludge pumping have large rubber ball valves in the suction and discharge and it is obvious that they cannot operate very long without catching a stick, seed or some other object that will prevent proper seating. The pump, then, simply breathes back and forth through the opening until cleaned by the operator. This means taking off the caps and prospecting by hand in the filthy mess to find the offending object. In a short time sand and other abrasive materials in the sludge wear the balls down and some day when the sludge is heavy and the friction high in the discharge line the suction valves will be pushed through the seats and down the pipe. The cure for this situation is not pleasant.

But that is not all that happens to a piston sludge pump. The cylinders are packed around the piston to prevent leakage; the pistons working up and down through this packing carry some abrasive material into the packing where it lodges and continues to grind away at the piston, which in a comparatively short time becomes hollow in the center of the stroke. When this condition develops it is impossible to pack the pump successfully and at each stroke sludge will hit the ceiling. The trouble might be remedied by covering the motor, enlarging the drain from the building and letting it spurt, or removing the pistons and having them straightened on a lathe. The pistons will stand about two cuts on a lathe, after which sleeves or new pistons must be installed. Pistons of harder material could be made but this

* Presented Before the Ninth Annual Spring Conference of the California Sewage Works Association, Stockton, April 23–24, 1937.

would not eliminate the valve trouble. Whenever equipment of this kind is installed it is my guess that it will eventually provoke the curse of some operator.

Diaphragm pumps are not above reproach. They have the same valve trouble plus the temperamental and easily broken rubber diaphragms.

Centrifugal pumps of the two-port end-suction type give fair service but are by no means perfect. The impellers wear altogether too fast in sludge that contains only small amounts of sand and the seal rings between volute and impeller soon become loose enough to pack with matches, hair and rags, which act as a brake upon the impeller. Centrifugal pumps for sludge work should be equipped with hard, tough impellers and seal rings and be designed, as far as possible, to prevent clogging of the annular ring between impeller and volute. Unless otherwise specified they will probably be equipped with bronze shaft sleeves, the bronze being cheaper. Shaft sleeves in centrifugal sludge pumps should be of the hardest material because of abrasive substances in the sludge that lodge in the packing around the shaft. Of course, a centrifugal pump must be of suitable size, not less than 4 inches. A 6-inch pump will give less trouble from clogging. Variable speed is essential.

There is a newcomer in the sludge pump field which combines a screw feed with centrifugal features. The screw is intended to cut up the coarse material and pass it on to the centrifugal impeller. Now, since primary sludge contains a large proportion of abrasive material it seems apparent that any cutting device will not long retain its cutting edge and when the cutting edge is destroyed, the screw feature simply becomes an obstruction in the suction, around which rags may wind.

All centrifugal sludge pumps should be set lower in elevation than the source of supply. A suction lift applied to sludge, and more especially digested sludge, is fatal, because all sludge is charged with gas and when partial vacuum forms in suction the sludge effervesces, releasing enough gas to cause the pump to operate poorly or killing the pumping action entirely. Setting the sludge pumps low facilitates the priming and makes unnecessary the installation of priming equipment which requires maintenance.

Sewage Pumps.—End suction pumps, both vertical and horizontal, with two-port, inclosed trash impellers, have been widely used for pumping sewage for many years. Though they are well established, they must come in for their rap. Vertical pumps have the disadvantage of a longer shaft, which requires more bearings. Vertical shafts give rise to lubrication troubles. If sleeve bearings are used and lubricated with oil, the oil does not reach the bottom bearings for several minutes after the unit has been started but continues to flow down the oil pipes for several minutes after the unit has been stopped. The excess oil plus the oil from the bearings farther up the shaft usually finds its way onto the pump room floor. If cup grease is used the operator

is required to do an extensive amount of climbing to screw down cups. If ball bearings are used, the trouble accompanying these bearings is incurred. About the only advantage to a vertical pump is when a pump must be installed directly in a wet well. If a dry well is provided and space is not out of the question, there is little defense for the installation of a wet well pump.

The close-coupled horizontal pump and motor, equipped with split sleeve babbit bearings, using oil for lubrication, is, without doubt, the most dependable, trouble-free unit. Sewage pumps should be set as low as possible to facilitate priming. Sewage, of course, will take a suction lift and the problems of sludge pumping do not apply.

All end-suction pumps, either vertical or horizontal, have the disadvantage of end thrust. This makes necessary the installation of a thrust bearing.

As in the case of sludge pumps, there is a newcomer in this field. This pump, a comparatively recent development, is of the double suction type. Four ports are provided, two drawing from one side and two from the other. This should exert an equalized suction pull upon the impeller and cause it to float between the opposing forces, thereby making any thrust bearing unnecessary. This is ideal, since in a horizontal position, with the shaft running straight through the impeller, both bearings can be split-sleeve babbit with oil-ring lubrication. The shaft, by passing straight through the impeller, does away with all overhang and holds the impeller more rigidly in position thus preventing it from whipping. This pump is deemed suitable only in large sizes and probably could not be applied to sludge pumps of small sizes. Rags might possibly wrap around the shaft in smaller sizes, but in large sizes it is fair to assume that this would not occur.

Bearings.—Sewage treatment is a perpetual proposition and, therefore, dependable equipment must be provided. No mechanical unit will ever be entirely trouble free and for that reason the equipment installed should be scrutinized with the thought of quickly effecting permanent repairs. Bearings are one source of trouble and therefore the most dependable type should be used in sewage equipment. This, in my opinion, is the split-sleeve babbit bearing that can be easily taken up if slack occurs. It is easy to line and easy to fit. There is little that can go wrong with this old standard. The worst that can happen to it is that it might overheat to the melting point of the babbit. Should this occur—though good operation should not permit it—the bearing can be repoured in a short time and with the aid of a little Prussian blue and a scraping iron it can be fitted and be back in service in a few hours.

The repair of ball, barrel and roller bearings, grouped under the heading of frictionless bearings, is quite another story. When a ball splits or the race becomes worn or chipped, causing the bearing to be noisy or to heat, there is nothing to do except replace it. Since these bearings come off over the end of the shaft this means taking the machine down with more expense and longer delay.

Full circle or solid sleeve babbit bearings are criticized for the same reason as frictionless bearings; they have no take-up and must be removed via the end of the shaft.

There are, of course, many places where ball bearings are essential and it is not intended to damn them utterly. In sewage equipment, weight, beauty and size are of little importance when compared with dependability, ease of operation and accessibility for quick repairs.

Submerged Equipment.—Now for a discussion of plant equipment that is submerged or inaccessible. There will, of necessity, always be some mechanical units in sewage treatment partially submerged in sewage or sludge, but unless the particular function is essential and can be accomplished in no other reasonable manner, submerged equipment should be avoided. Take for example sludge stirring mechanisms in digesters. If anything goes wrong below the sludge level, it means putting the tank out of service to reach the unit and begin repair. The natural overturning of sludge in digestion seems to provide all the mixing necessary and the value of additional mechanical mixing is questionable. After thorough investigation and trial, mixing in the digesters of the Los Angeles County Sanitation Districts' plant was discontinued. Two years have since elapsed without indicating any difference in results. It seems that this type of submerged equipment might be eliminated. It has been held that the rotating plows concentrate the sludge; if so, about the best they can accomplish is a saving of a day or so in time on the sludge beds, because digested sludge will drop all of its drainable water in 48 hours; the remainder must be evaporated. The reward seems scarcely worth the means.

In the class of submerged equipment the various types of sludge collecting machinery must be scrutinized. Necessarily the sludge collecting equipment will be partly submerged, but, other things being equal, those types are to be preferred which have the fewest submerged parts requiring maintenance. The accepted types of clarifier mechanisms, either center or rim drive, are satisfactory from this viewpoint. They are dependable because they have few working parts and all driving mechanism is easily accessible. Another sludge collector with all moving parts accessible is the traveling bridge. This type is adapted for use in rectangular tanks. The bridge type lends itself to the application of mechanical skimming.

In contrast to these, the chain-flight types of sludge collectors have more mechanism under water where the operator cannot see the equipment. Often the first sign of trouble in this type is when a slat floats to the surface indicating that the chain has jumped a sprocket. Rags wrap around the shaft and cause no small amount of trouble. There is no way to get at this submerged equipment other than to dewater the tanks. The wooden flights, dragging on concrete floors, wear badly even when iron shod, and must be replaced from time to time. The blades of the standard clarifiers will outwear them ten to one.

Maintenance of submerged equipment is dirty work. It is not that operators shy at a day's work or the performing of some dirty job. At

best there will always be numerous disagreeable jobs to be done in connection with sewage treatment. The operators do object to plant design which makes necessary dirty work which could be avoided. Whether it is admitted or not there is a definite health hazard connected with the treatment of sewage and the less the sewage is contacted by the operators, the lower that hazard will be.

Observations

It is common knowledge that digestion tanks have a tendency to foam and they are almost certain to do so sometime during their life. But I have yet to see any means provided in the plant design to care for this phenomenon, such as special outlets leading to a confined area provided for the purpose of catching the overflow. Instead the tanks foam all over the plant site and the operator must handle the situation with some temporary expedient.

Many sludge lines are laid with no cleaning outlets or with outlets in the wrong location. Pipes are laid through soft backfill that will settle, disjointing the pipe or throwing it out of line, causing gas pockets to form which will give pump priming trouble. Pipes of all description are cast in concrete walls. If the backfill outside the building settles and breaks the pipe at the wall, which it usually does, there is no way to make repair except to chip out the pipe. If the wall is thick and the concrete of good quality it may take a couple of days to accomplish this. Pipes should never be cast rigidly in a concrete wall. Daytons, Dressers or straight sleeves should be provided so the pipe can be withdrawn if necessary. All valves should be rising stem, quick opening, either hydraulic, pneumatic or lever-operated.

Exposed pipes that are subjected to variable temperatures have a tendency to crawl, and in leaded work cut nipples that have no leading bead will crawl apart and finally disconnect themselves. They must be held in place.

Pump room floors often have insufficient drainage or none at all, with small, undersized sumps to care for the floor washing. A great deal of thought should be given the features that make possible the maintenance of cleanly conditions about the plant. Ample pumping capacity should be provided for use from the pump room floor to care for any serious leak that may occur from unforeseen emergencies.

We sometimes see ladders instead of stairs. If ladders must be installed they should never be of the manhole step variety, with no side rails to prevent greasy boots from slipping off. Much productive thought can be given to safety features.

From time to time phenomenal storms will occur which tax the plant beyond its capacity. At such times, though rare, the facilities to care for these contingencies may relieve the operator of long hours of unnecessary labor, competing with high water. If no provision has been made to care for these unusual occasions and the operator loses the fight, the plant may be submerged. Should the plant be submerged,

are the most important mechanical units vulnerable? When high water occurs the scouring of the lines yields an increase in bar screenings, therefore mechanical bar screen cleaners should be capable of increased speed to prevent clogging upon such occasions.

Some pump houses are cramped beyond reason. It would appear that the equipment had been installed and the concrete building poured around it. Removal or repair of the equipment under such circumstances is difficult. On the other hand, we see some plants all spread out, requiring an unnecessary amount of traveling from unit to unit. This extra distance requires time and energy and reduces efficiency. Another common fault with design is that there is too much up-and-down provided. Running up a flight of stairs every few minutes lessens the amount of useful work an operator can perform. Designers seem to have a fixation that steps are necessary, or: "What are a few steps if you don't have to climb them yourself?"

Now, it is conceded that few men charged with the design of sewage treatment plants have had the benefit of operating experience; they, therefore, do not think in terms of operation. Those who do not possess this dual training would do well to consult with operators of long experience. The amalgamation of the experience of the operator with the training of the engineer will go a long way toward producing a smoother treatment plant. It so happens that a great many of the things that make for smooth, trouble-free operation do not add to the plant cost. Largely they are the product of sufficient forethought, coupled with a thorough experience in operation.

The designing engineer assumes a heavy responsibility in the planning of a sewage treatment plant. Once the plans are made and the plant built, the die is cast and the operator can do very little about it. His province is to maintain that which has been provided. There is a long list of indictments which the operators bring against the engineers. The California Sewage Works Association, through its caravans, has caused a parade of these errors to pass in review in bold relief. The disheartening part of it all, from the operator's standpoint, is that we see the same mistakes made again and again. Why is unsuitable mechanical equipment installed? As a matter of fact, equipment is usually purchased through competitive bidding and if the specifications are not rigidly drawn to insure exactly the type of equipment desired, the important small details will be neglected. It is not entirely unheard of to find some mechanical ignorance displayed by the engineer regarding the correct type of equipment to purchase. A product cheaper in cost and which may appear acceptable to the engineer may be offered and taken.

As Mr. Kennedy stated last year at Santa Monica, the engineer is at times handed the cloth and told to cut the best suit he can from it. That the engineer succeeds in so doing is evidenced by many fine plants throughout the state.

SCREENS AND ROLL PRESSES

By J. H. Van Norman

Operator, Hyperion Plant, Los Angeles, Calif.

All the sewage of the city of Los Angeles, except that of San Pedro, is disposed of at the Hyperion Screening Plant. Dorreo fine screens are used for this purpose. There are ten (10) units in use at this time. Five units were installed in 1925 and five more units were added in 1930. All screens are 14 ft. in diameter by 12 ft. in length. Other mechanical equipment includes de-watering elevators, mechanical rakes on coarse bar screens, air compressors, incinerator equipment, including roll press for de-watering screenings, oil pumps, electric recording pyrometer, air operated sluice gates, air operated effluent gates, electrically operated butterfly gate in main outfall line to ocean and numerous electric motors of various types and sizes. Considerable trouble was encountered with the shaft bearings on the five screens first installed. These bearings were of the roller type. Bronze sleeve bearings were designed and installed and have proven satisfactory. As the space for the roller bearings was limited, 8 in. diameter by 8 in. long sleeve bearings were as large as could be used to replace roller bearings. In designing the five units installed in 1930, sleeve bearings, 10 in. diameter by 10 in. long were used. An important improvement was made when the five units were installed in 1930. This was the use of the automatic log clutch between the driving motor and the reduction gears. This clutch permits the electric motor to attain full speed, then starts to pick up the load gradually without shock to motor or gears. Perforated screen plates have given very little trouble and replacements have been few. These failures were caused by boards or chunks of concrete falling into screen pits and breaking plates. One main shaft had to be replaced and this, of course, called for much time and labor to remove and replace all bolts, plates, spiders, bearings, and other parts. The mechanical rakes now in use are operating satisfactorily. Several changes have been made since the first installation. The entire driving unit, including the motor, is enclosed in a waterproof housing and the gears and drive chain run in oil. The arms and rake blades run in the sewage and must be replaced from time to time as painting does not protect them.

The ¼ in. steel plating on the elevator housings last about five to six years and must be replaced. No. 830 Rexley bushed chain is used for the bucket elevators and it lasts about 18 to 24 months. Brass reinforced elevator buckets suffer mostly from excess sand during the winter months and replacements and repairs are necessary.

Compressed air for ejecting screenings and for various other uses is furnished by an Ingersoll-Rand two-stage type X R B compressor of about 600 cu. ft. capacity. By the use of a low carbon content oil and cleaning the valves when necessary, this machine operates 20 or more hours per day and requires very little attention.

The Morse-Boulger destructor is equipped with a Louisville press for de-watering screenings before incineration. The perforated endless steel belt that carries the screenings through the rolls is a weak part of the incinerator plant. Fruit pits, golf balls, bones and other solid objects that find their way into the sewer, punch holes in the belt and break down the hinges. Sand on the screenings reaches the bearing of the press and it has been necessary to replace roller shafts and re-babbit bearings several times.

Variable speed, wound-rotor slipring induction motors were used on the five screens first installed. These were unsatisfactory because the gases attacked the copper rings, causing excess brush wear and poor contact. Constant speed induction motors are now used and are satisfactory.

Main bearings on the screens and bearings on the elevator drive shafts are lubricated with chassis grease or high pressure grease. A one-shot lubrication system was installed in 1930 serving five screen units; it has proven quite satisfactory.

Cleaning screens is an important duty at Hyperion and part of the ten screens are cleaned every day, except Sunday. Steam is used at about 100 lb. pressure. We also have a "gang roller" designed by one of the operators that cleans out the slots in the screen plates. It consists of several blades of steel so designed as to clean several rows of slots at a time and is pushed along like rolling a wheel.

The mechanical maintenance of a screening plant requires the efforts of trained men. The severe conditions under which the machines and equipment operate, being attacked by the gases and needing replacement and repairs regularly and the electrical wiring, fuses, switches and motors must be taken care of, as any exposed copper will not last long around a sewage plant. In the use of oils and greases I find the best none too good. A poor grade of grease used in a one-shot lubrication system will separate and the soap stock in the grease will plug up the line.

In a plant the size of the Hyperion disposal plant, I believe the best results can be obtained if you have included in the personnel, in addition to the plant operators, a good machinist and an electrician.

FERRIC CHLORIDE FEEDERS AND COMMINUTORS

By Alfred W. Wyman

Superintendent of Plant, Pasadena, Calif.

Two of three pieces of equipment installed at the Pasadena Plant this year may be of interest.

In the preparation or conditioning of sludge for filtering, chemicals in dry or liquid form are used. To control the addition of chemicals, it is necessary to provide some accurate means of proportioning the amount of chemical to the weight of sludge filtered.

For some years batch dosing was employed at Pasadena and was never satisfactory. Because of the time element in filtration, chemicals gradually lose their effectiveness and consequently slow down the filtering rate toward the end of each batch.

Recently Wallace and Tiernan, with the cooperation of Sparling Meter Co., designed and built a feeder combined with a meter which can be depended upon to feed ferric chloride in any proportion to the rate of sludge flow. Such a machine has been very satisfactory in solving one of our problems, and is well built to withstand the corrosive effect of this chemical. The Wallace and Tiernan Feeder in combination with a Sparling Meter will prove a fine asset to any sewage works desiring accurate control for the use of ferric chloride.

Another installation this year, and one that we have needed for a long time, is a pair of comminutors. With such a name one ought to expect most anything, and they are living up to it. These comminutors, or grinders as we more often call them, are arranged in two channels controlled by two 48 in. gates. Each comminutor, 36 in. in diameter with 3/16 in. slots, is driven by a 5 H.P. motor. Very rugged in construction, with large bearings above the water line, these machines run as smoothly as a clock. Each has a capacity of over 15 m.g.d., and in the six months they have operated have needed no repairs and very little attention.

Everyone asks what is wrong with a piece of equipment rather than the good features. In my opinion there is nothing wrong with these comminutors, and the only missing feature is a knife that will cut rags in small pieces. These comminutors do cut rags as easily as other materials in sewage, but the rags are cut in strings 3/16 in. wide by one or two feet long. These strings are a nuisance as far as pump impellers are concerned, and the only remedy we have found is a bar screen behind or beyond the commuinutors. Inspection of the stellite cutters indicate no chipping or apparent wear or dullness.

The cleanliness and improved appearance of this machinery over our old system is very noticeable.

Expense for screenings disposal is practically eliminated and the comminuted material has added about half a ton of dry sludge per day to our fertilizer output. Nitrogen content has remained the same as before the addition of this material, much to our surprise and advantage.

We have also put into service a new Oliver vacuum filter, with which most of you are familiar. It is practically the same as our other three, except for a few improvements. A new building now houses this equipment.

An addition to the plant in the near future is anticipated, increasing our capacity by approximately 3 m.g.d. This addition will include a mechanically cleaned bar screen.

AUTOMATIC CONTROL OF SKIMMERS, SLUDGE PUMPS, GAS ENGINES AND WASTE GAS

By H. M. Ely

Chief Operator, Disposal Plant, Ontario, Calif.

In the operation of a modern sewage disposal plant, it is necessary that we have a large amount of mechanical equipment, and the efficient operation of the plant depends largely on how well this equipment functions. The slogan of the National Implement Dealers a few years ago; "Good equipment makes a good farmer better," surely applies to the sewage plant operator and his equipment.

When one man has complete charge of the operation of a plant, mechanical, laboratory, and other phases, it is necessary that he plan each detail of his work in order to have plenty of time to meet all routine duties.

With this in mind at our plant in Ontario, we have endeavored to make everything automatic as nearly as possible, and still maintain a high degree of efficiency in operation.

I want to speak of some of our automatic devices and explain how they function.

Our primary clarifier is equipped with an automatic skimmer and scraper, manufactured by the Hardinge Company. This is controlled by a General Electric twenty-four hour clock, making the trip across the clarifier once every hour from 7:00 A.M. to 9:00 P.M. and about once every two hours for the balance of the night, making a total of twenty trips over the tank in every twenty-four hours. This, together with the next device, of our own manufacture, keeps the primary clarifier in excellent condition.

In connection with our automatic skimmer and scraper, we have put on the side of the clarifier an electric switch which controls our sludge pump, the latter connected to the pump at the front end of the clarifier. Every time the skimmer passes this switch it starts the pump which runs for three and one-half minutes, or a total of ninety minutes each day. We have found that by following this schedule, we are enabled to keep our primary clarifier in excellent condition without overloading it at any one time with supernatant liquor from the digester; which we all know is one of the serious difficulties encountered in the operation of activated sludge plants.

It is the writer's firm belief that upon the successful operation of the primary clarifier rests the operation of your whole plant, and it is with this end in view that we have placed this second device in operation. We have been more than pleased with the results obtained.

Another of our automatic fixtures performs with our gas engine. This engine is operated on a twenty-four hour basis, running an air blower. We knew the habits of gas engines, that at some unexpected time they might stop, especially when the attendant is away. We found it necessary to provide some means to start an electric motor and blower in case the engine should fail. First, we placed a check

valve in the main air line leading from the engine, connecting it by a spring switch to our main motor and blower. If the engine stops, the check valve closes and the arm with the balance weight releases the switch and the electric motor starts, thus keeping up the supply of air to the aeration tanks. To date, this has functioned perfectly. On five separate occasions, I have returned to the plant and found the engine stopped and the electric motor carrying the load. This gadget alone has practically made our plant a one-man plant.

Our engine is further protected by an automatic temperature cut-out to prevent the engine from over-heating, as well as an automatic oil pressure gauge, which stops the engine if any obstruction comes in the oiling system. The latter gauge has been one of the causes of the engine's stopping by reason of an oil line inside the engine coming loose and leaking. Serious damage probably would have been done on the engine if this device had not functioned.

Still another gadget disposes of our waste gas. On account of the varying quantity of gas from the digestor, it was necessary to provide some means of taking care of it when in excess of our needs. We installed a lever check valve in the waste line and connected it to a trip lever on top of the gas holder. As the dome on the gas holder rises it opens the check valve, allowing the gas to escape to the burner. A pilot line attached behind the check valve keeps a pilot light burning at all times. In this way we have substantially lessened the danger of fire, and odor of escaping gas. It has also made it possible for us to pass all the gas we make through our meter. Thus we know each day just how much gas has formed, been used, and wasted.

These four automatic devices have made it possible to operate our plant not only efficiently, but economically, and this accomplishment makes the operator feel, as he leaves the plant, especially at night, when it is alone for twelve hours or more, that because of these devices, everything is functioning properly.

MECHANICAL FILTRATION OF EFFLUENTS*

By S. I. Zack

Sanitary Engineer, Filtration Equipment Corporation, New York City

Introduction

Sewage is composed of impurities in the form of suspended, colloidal and dissolved solids of organic nature. When discharged into a river or other receiving body of water, unless the currents are swift enough to carry them on, the heavier suspended solids settle out in the immediate vicinity and the finer solids farther downstream. The colloidal solids coalesce and coagulate and finally may also be subject to settlement. Such deposited solids, together with organic matter in solution, are subject to putrefaction if not supplied with sufficient oxygen to permit aerobic stabilization or oxidation.

The extent of nuisance created depends on the rate of decomposition as against the available forces of oxidation. Conditions are aggravated when sludge deposits, accumulated in a confined area, have remained stagnant during the winter period of biologic inactivity, and suddenly become subjected to rapid decomposition with the higher temperatures and lower dilutions of the summer period.

Purpose and General Methods of Sewage Treatment

The purpose of sewage treatment is to remove impurities or change their chemical or biologic state so that the natural forces of oxidation of the receiving body of water can adequately act upon the residual products in the effluent before nuisances are created. Until recently modern sewage treatment generally comprised:

Primary Treatment, involving the removal of visible solids, accomplished by grit chambers, screening through slotted or bar screens and sedimentation.

Secondary Treatment, accomplished by some form of biologic oxidation such as activated sludge or trickling filters. In secondary treatment, the colloidal and non-settleable solids are coagulated to a point where they can be readily separated and removed from the liquid.

Secondary sedimentation provided the means for separating solids from liquid before discharge of the final effluent. Since the reaction is reversible, these solids may again break down into putrefactive forms, in the absence of sufficient oxygen. The amount of such suspended solids escaping furnishes one of the measures of the quality of the effluent.

There has been a wide gap between treatment afforded by primary and that which was possible by secondary methods, especially when

* Presented before the Ninth Annual Spring Conference of the California Sewage Works Association, Stockton, April 23, 1937.

measured in terms of dilution water required for the disposal of these effluents without nuisance. Revival of chemical treatment and the development of automatically cleaned effluent filters has placed new tools in the hands of sanitary engineers for the purpose of providing intermediate degrees of treatment.

Intermediate Treatments

Chemical treatment coagulates the colloidal and finer suspended solids so that they readily separate from the liquid and can to a large extent be removed by settling. As much is therefore accomplished with respect to these solids as in biologic methods, but chemical treatment falls short in the actual treatment of impurities in dissolved form. The oxygen required to stabilize a chemical effluent therefore is greater than for a biologic effluent but is much less than for primary effluents.

Mechanical effluent filters or strainers, with which this paper deals at considerable length, provide the other important tool. Effluent filters afford a direct means of treating and improving either primary, chemically treated or final biologic effluents by straining out solids that fail to settle. Several types of effluent strainers have been advocated or used for treating effluents. These consist of modified gravity-type water filters, with sand or crushed coal (anthrafilt) filter medium, designed either for rapid back washing, or utilizing various types of surface or subsurface washers, string discharge rotary vacuum filters, using paper pulp as a filter aid, and the automatically cleaned, thin bed, upward or downward flow Laughlin magnetite filter.

Attempts to filter raw or settled effluents, without chemicals, by means of gravity-type water filters, using standard size sand, have met with little success. Known experience in this country indicates permanent clogging. However, Dr. Mahr in Germany has reported some very interesting data covering a period of nine months on experiments, with a coarse grained rapid backwash type gravity filter, for straining settled effluents. Rather complete removal of settleable solids at 0.82 gal. per sq. ft. per min. filter rate was obtained on 1 to 2 mm. sand. This was considered the most satisfactory rate of operation since the efficiency of the filter was appreciably reduced as the filter rate was increased; and further reduced by an increase in size of sand grains used for filtering. Time between washings to reach a 4.1 ft. loss of head at a rate of 0.82 gal. per sq. ft. per minute was 25 hours, filtering through 2 to 3 mm. sand. At filter rates of 1.47 through 1 to 2 mm. sand, backwashings were about every 8 hours.

Experiments have been conducted at Atlanta, Ga., York, Nebraska and San Diego, Cal., on filtering chemical effluents by means of some modified forms of gravity-type rapid backwash filter. Both sand and crushed coal were tried at Atlanta. Effective removals of suspended solids were accomplished, but concentration and character of suspended solids in liquor that could be applied and rates of filtration were limited by the frequency of backwashing required.

Data have been prepared by Alexander Potter to show the average results of experiments on sand filtration of chemical effluents at Atlanta. The results indicated that 37 p.p.m. of suspended solids were removed from an influent of 45 p.p.m., and 26 p.p.m. out of 34 p.p.m. suspended solids, when using "anthrafilt" as a filter medium. These tests indicated filter runs of 12 hours at rates of 2.0 gal. per sq. ft. per min. and runs of 3 hours at rates of 3.5 gal. per sq. ft. per min., to develop less than 5 ft. loss of head. The range of suspended solids in the effluent applied to the filter was from 9 to 75 p.p.m. Comparative data also indicated that twice as many backwashings were required for filter influents of 57 p.p.m. as for 18 p.p.m. suspended solids. The filter medium had an effective size of 0.45 mm. No relation was found between filter rates of ratio 1 to 4 and suspended solids removal. It was concluded in these tests that for filtration of chemical effluents carrying in excess of 75 p.p.m. suspended solids particular attention must be given to backwashing facilities.

Rapid backwash type filters are installed in small plants for operation on activated sludge effluent at Grand Canyon National Park and Barrington, N. J., but no information is available on performance or frequency of backwashing over any extended period.

The most comprehensive and complete data on performance over continuous extended periods suitable for design purposes are available from pilot plant size and full scale plant operation of automatically cleaned magnetite filters.

Description of the Magnetite Filter

The magnetite filter consists of bed of magnetite ore about three inches thick supported on a fine mesh of phosphor or silicon bronze (non-magnetic) wire. Fine suspended solids contained in primary or secondary settled effluents are caught between the particles of ore thereby clarifying these liquors in their passage through the bed. When the spaces of interstices between the grains of ore become partly choked with the intercepted solids, the filter is automatically washed by a cleaner which passes slowly over the ore.

The cleaner consists of a bottomless box or caisson which carries a centrifugal pump, and a solenoid or electro-magnet. The solenoid is alternately magnetized and demagnetized so that a narrow strip of ore is intermittently lifted off the wire screen and allowed to fall back. At the same time the small centrifugal pump maintains a head level which causes the liquor from beneath the bed to rush through the moving ore and effectively clean the portion of the bed lifted and agitated by the solenoid. The wash water containing the impurities from the ore is caught up by the pump and passed back for retreatment or other disposal.

This filter is adaptable for upward or downward flow filtration. In upflow it is usually supported on brackets on the inside rim of circular tanks. A number of plants using this type of design are either in operation or under construction. Upflow filters can also be de-

signed for rectangular sedimentation tanks. The downward flow magnetite filter is a new development and was first demonstrated at Coney Island by means of a small circular filter. More recently this principle has been applied to a rectangular arrangement with reversal of the cleaning mechanism. An upflow filter within a tank provides a uniform distribution of effluent take-off over a large area, thereby retarding upward velocities. Such factors as the following, however, often make the downflow filter a desirable unit:

1. Flexibility of the filtering unit separated from the settler.
2. Size of grain not limited by the practical minimum screen opening as in upflow, because unfiltered liquor first reaches the washable filter medium.
3. Higher efficiency of removal possible with finer grain.
4. Filter medium washed with filtered liquor.
5. Less limitation on maximum loss of head, making possible somewhat higher filter rates.

Magnetite Filter Installations

The installations of magnetite filters in operation or under way are shown in Table I.

The pioneer plant to employ the combination of chemical treatment and magnetite filters is at Dearborn, Michigan. This plant has been in operation since 1932 and uses chemicals throughout the year.

The Perth Amboy plant, originally designed for chemical treatment during the entire year, now finds it necessary to use chemicals only during the summer months. The filter, therefore, functions as a strainer on chemically precipitated liquors during the summer and on plain settled effluent during the remainder of the year. This type of seasonal chemical treatment is also to govern the operation of plants at Lakeland Institution, Camden, N. J. and Elmira, N. Y. (Fig. 1), which are already in operation and at Denver, Colorado and the Minneapolis-St. Paul Sanitary District, which are under construction.

Filters at Goshen, Ind., and Chillicothe, Ohio, strain the effluent from plain settling tanks. Columbus Grove, Ohio, Atlanta, Ga., and Southerly Plant, Cleveland, will use filters for polishing off the trickling filter effluents. At the Southerly Plant, Cleveland, partial activated sludge precedes the trickling filters and magnetite beds (downflow) in separate structures following the trickling filters. In this case the effluent filters are substituted for humus tanks. In the other installations the humus tanks, preceding the effluent filters, have been reduced in size.

The magnetite filters at Denver, Minneapolis and Cleveland are downflow in a separate structure, whereas, the others are upflow built on the inner periphery of the settling tanks.

All the plants except Denver have magnetite of 0.85 mm. grain size. The Denver magnetite will be about 0.60 mm. Finer magnetite was chosen to provide an additional safeguard in the re-use of the final ef-

TABLE I.—*Status of Magnetite Filter Installations*

City	Date Placed in Operation	No. of Units	Width of Bed, Ft.	Size of Tank or Structure	Type of Service	Flow M.G.D. Each Unit	
						Design	Present (Approx.)
Upflow—Circular Filters							
Dearborn, Mich.	March 1932	2	8	60 ft. diam.	Chem. Treat.	8.00	3.00*
Perth Amboy, N. J.	June 1935	2	12	80	(Chem. Treat. 3 mo.) (Plain Sett. 9 mo.)	10.00	4.00*
Lakeland, N. J.	July 1936	2	3	21	(Chem. Treat. Plain Settled)	0.75	0.30
Goshen, Ind.	Sept. 1936	1	6	45	Plain Settled	1.75	1.50
Columbus Grove, Ohio	Nov. 1936	1	3	21	Trick. Filter Eff.	0.50	—
Chillicothe, Ohio	Nov. 1936	2	5	42	Plain Settled	3.00	1.00
Elmira, N. Y.	Mar. 1937	2	8	60	(Chem. Treat. Plain Settled)	8.00	—
Atlanta, Ga.	Under Constr.	1	12	100	Trick. Filter Eff.	14.00	—
Greece, N. Y.	Under Constr.	2	4	35	Activated Sludge Eff.	2.00	—
Downflow—Rectangular Filters							
Denver, Col.	Under Constr.	6	12	200 ft. long	(Chem. Treat. Plain Settled)	54.00	—
Minn.-St. Paul, Minn.	Under Constr.	8	16	245 ft. long	(Chem. Treated Plain Settled)	134.00	—
Cleveland (Southerly Plant)	Under Constr.	3	16	225 ft. long	Trick. Filter Eff.	40.00	—

* One clarifier and filter in operation.

fluent for irrigation, particularly because it is believed this size will strain out dysentery amoeba.

Performance on activated sludge effluent was demonstrated in a seven months test, from June, 1934, to February, 1935, with a 3 ft. wide upflow filter on a 20 ft. diameter tank at the North Side Plant of the Sanitary District of Chicago.

Greece, N. Y. now has under construction two 4 ft. wide upflow magnetite filters in 35 ft. diameter final activated sludge settling tanks.

Comparative tests were made at Coney Island (1934 to 1935) with two tanks in parallel, one without and one with a filter, both on plain settled and chemically precipitated effluents.

FIG. 1.—Magnetite filters and clarifiers at Elmira, N. Y.

The use of magnetite filters for trickling filter effluents was investigated experimentally at Atlanta in 1935.

Tests with a circular downflow filter carried on during 1936 were recently completed at Coney Island. Similar tests are now under way with a small rectangular downflow filter to check the applicability of important features of mechanical design.

OPERATING AND ANALYTICAL RESULTS

Table II shows overall efficiencies of filtration through magnetite filters, with and without chemicals.

Chemical costs to coagulate the sewage have ranged between $4.00 and $5.00 per M.G. at Dearborn and about $8.00 per M.G. at Perth Amboy. Perth Amboy sewage is highly industrial and very variable in character. In the course of a day, pH of the raw sewage may vary from 2.0 to 9.0.

Results at Goshen were obtained by a special test supervised by Mr. E. Hurwitz, Sanitary Chemist, Chicago, in cooperation with the City of Goshen and Mr. Walter Bemis, Consulting Engineer. During the first part of the test serious surging occurred due to intermittent operation of a 3 m.g.d. capacity pump which started and stopped about five times an hour, running only a few minutes each time. Improved results were obtained by continuous operation afforded by a 1.5 m.g.d.

TABLE II.—*Results Accomplished by Plants with Magnetite Filters*
Overall efficiencies of filtration through magnetite filters

Plant	Period	Flow M.G.D.	Chemicals used Lb. per M.G.		Suspended Solids			B.O.D.		
			Lime	$FeCl_3$	Inf.	Eff.	Pct. Red.	Inf.	Eff.	Pct. Red.
Chemical Treatment										
Dearborn....	1935	2.7	224	307	388	22	95	189	40	79
	1936	2.4	160	208	339	27	92	185	51	73
Perth Amboy.	July-Aug. 1935	2.8	659	252	240	28	89	257	100	60
Non-Chemical Treatment										
Perth Amboy.	1935 (10 months)									
	1936	3.8			223	65	71	205	144	30
Goshen.....	Nov. 27, 1935									
	Jan. 8, 1936	1.3			206	76	63	152	80	47
	Jan. 4–8, 1936	1.4			181	58	68	139	65	53
Chillicothe *..		1.0			417	80	81	580	215	63

* Average of a number of grab samples in December, 1935, and January 1936.

capacity pump. This improvement is shown in Table II by the results from January 4th to 8th inclusive.

At Chillicothe the plant routine has not yet been established, and the results included are from scattered grab samples only, but serve as an indication of the efficiency of settling and straining a very strong domestic sewage.

Analyses of samples below the screen in the upflow type, and of the influent to downflow filters, compared with analysis of effluents, furnish a basis for estimating the suspended solids actually removed by the filter. These results summarized in diagrammatic form are shown in Fig. 2. The removals for each type of effluent fall along a different straight-line curve and are proportional in each case to the solids reaching the filter.

Comparative tests were made at Coney Island between a 6 ft. diameter tank equipped with magnetite filter and another tank without a filter. In the non-chemical tests, it was found that about 20 per cent higher removal of suspended solids was obtainable by filtering after 2 hours of sedimentation. It was also learned, on that particular type of sewage, that 60 per cent removal was possible by settling 1 hr. followed by straining, as compared with 45 per cent by settling alone for 2 hours.

With chemical treatment it was found that $3.00 per m.g. expenditure for chemicals in the plain settling tank accomplished the same suspended solids removal as a filter-equipped tank without use of chemicals. Ninety per cent removal of suspended solids was obtained

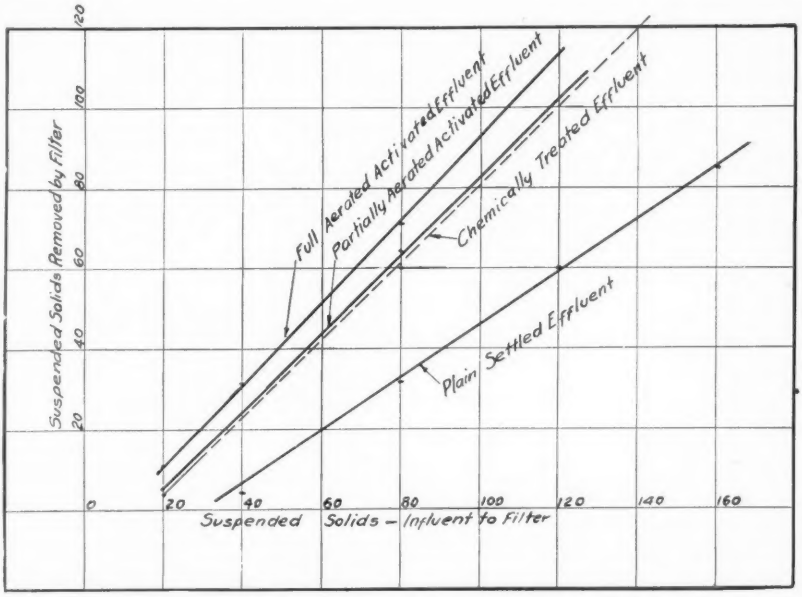


FIG. 2.—Curves showing relation between suspended solids reaching magnetite filter and that which is removed. For straining various effluents.

by settling and filtering, at a cost of $6.00 per m.g. for chemicals, whereas $12.00 per m.g. was required to obtain the same treatment in a tank without a filter. For the same amount of chemicals a higher degree of treatment was obtained by the tank with a filter. Chemical costs are based on lime at $12.00 per ton and $FeCl_3$ (anhydrous) at $40.00 per ton.

These data are significant because similar conclusions may be drawn from data by Damoose for experiments at Grand Rapids. The Grand Rapids data show that the filtered effluent contained 5 per cent less suspended solids after coagulation with 0.75 grains per gallon $FeCl_3$, figured at above price to cost $2.15 per m.g., than was obtained without filtration with 1.5 grains per gallon ferric chloride, amounting to $4.30.

The Grand Rapids results were obtained with a shallow filter bed strainer, which was frequently washed by hand.

Data reported by F. M. Veatch on test results obtained at York, Nebraska, with a small gravity type backwash filter, indicate that after coagulation with chemicals, worth $4.35 per m.g., with settling for 4.3 hours in primary and 5.7 hours in secondary settling tanks, the settled effluent, carrying from 28 to 100 p.p.m. suspended solids, was further reduced to a range between 8 and 26 p.p.m. by the filter.

Continuous filter rates at the plants in operation have not as yet reached the design capacity. Data on filter rates are, however, available from pilot plant operation and for brief periods on a large scale. Rates of 2.0 to 2.25 gal. per sq. ft. have been found most suitable for continuous operation of upflow filters on a normal settled sewage, but there is no marked deterioration in the quality of effluent for temporary rates up to about 3 gal. per sq. ft. per minute. The filter has been operated at rates as high as 6 gal. per sq. ft. per min., but frequent washing by one cleaner covering a relatively small area was required.

Magnetite grain sizes ranging from 0.4 mm. to 4.0 mm. were tested in a small circular downflow filter. The best effluents, averaging as low as 30 p.p.m. suspended solids, were obtained with fine magnetite at a 2 gal. per sq. ft. per min. rate. As the grain size or rate of filtering was increased the quality of effluent decreased. Very substantial removals were obtained, however, with coarse magnetite and high filter rates. Under this condition it was necessary to make a complete cleaning of the filter bed every twenty or thirty minutes.

Chlorine Demand of Filtered Effluents

An average reduction in chlorine demand of about 18 per cent was obtained by filtering out approximately 50 p.p.m. suspended solids. The raw sewage averaged 158 p.p.m., the settled unfiltered effluent 100 p.p.m., and the strained effluent 50 p.p.m. As much as 20 to 30 per cent reduction in chlorine demand was obtained by straining the settled effluent. On weak settled effluents the reductions in chlorine ranged from zero to 15 per cent.

Costs of Magnetite Filters

Contract prices of magnetite filters for installations bid separately from any other equipment, are shown in Table III. It is estimated that the annual cost, including fixed and operating charges for a plant of about 10 m.g.d. capacity, would be about $1.50 per m.g.

Estimates of operating costs indicate that magnetite filters will remove solids at a lower cost per ton than any other method in the same range of treatment. For example, on a raw sewage containing 200 p.p.m. suspended solids, 90 per cent can be removed by the activated sludge process at a cost of $35.00 per ton, or $26.00 per m.g. The magnetite filter makes it possible to remove about 15 p.p.m. more. The cost for removing the additional 15 p.p.m. is only about $25.00 per ton.

A trickling filter, operating at $26.00 per m.g. removes 85 per cent of the suspended solids, at a cost of $37.00 per ton. Twenty p.p.m. more is removed by a magnetite filter at a cost of only $18.00 per ton, for the additional removal. Similarly 50 per cent of the suspended solids can be removed by plain sedimentation, at a cost of about $30.00 per ton. The magnetite filter takes out 40 p.p.m. or 20 per cent more at a cost of $9.00 per ton for the additional suspended solids removal.

TABLE III.—*Cost of Magnetite Filters*

	No. of Beds	Total Area Sq. ft.	Design Capacity M.G.D.	Contract Price Installed*	Remarks
Goshen, Ind.	1	735	1.75	$14,500	Upflow in circular tanks
Chillicothe	2	1160	3.0	27,700	Upflow in circular tanks
Denver	6	14700	54.0	255,150	Downflow fine magnetite with rectangular in separate structure
Minneapolis-St. Paul	8	31230	134.0	516,390	Downflow coarse magnetite with rectangular in separate structure

* These figures show the additional cost of adding magnetite filters and supports, or separate structures.

CONCLUSIONS

1. Magnetite filters are operative on plain settled, chemically precipitated, activated sludge and trickling filter effluents.

2. Rates from 2 to 4 gal. per sq. ft. per min. are workable on downflow fine grained (0.60 mm.) filter beds and 2.5 to 6.0 gal. per sq. ft. per min. on coarse (0.85 mm.) beds when preceded by at least 1.0 hour of settling.

3. Effluent filters are economical from the standpoint of: positive savings in chemicals to accomplish a definite treatment, possibility of reducing size of tanks, production of a uniform effluent, improvement of preliminary or secondary effluents to prevent secondary deposition of solids in streams. All of these advantages may be difficult or costly to obtain by other methods in the same range of purification.

TRICKLING FILTER OPERATION RESULTS AT WORCESTER, MASSACHUSETTS

By Roy S. Lanphear

Supervising Chemist, Sewer Department, Worcester, Mass.

Dosing tanks are separate installations but they serve a definite purpose in connection with trickling filter operation. Routine operation at Worcester includes washing the tanks each Friday; blowing out all of the piping and cleaning and oiling the counters on Saturday. The counters are inexpensive Veeder units working with float attachments.

The tanks are covered during the winter. The life of the plank covers, which are creosoted, has averaged about ten years. The plank covers over the influent channel serve as a walk and are being replaced, as necessary, with sections of plank spaced ½-inch between the plank. It is hoped that such arrangement will afford longer life by releasing the moist air from below.

The automatic operating assembly of galvanized iron pipe has caused no trouble where near or above the maximum water level. The piping assembly, which extends down into the dosing tanks, has been replaced once in each tank, the first after seven years, the second after eight years and the remaining six after ten or eleven years. Pin holes develop in the pipes and the upright assembly is replaced between two convenient flanges. The cost of material for a single unit averages from $50 to $55; assembling labor, $20 to $25 and erection, about $10. According to these figures, protection of the new assembly should not exceed an expenditure of from $8 to $9 for one year of additional life. The condition of the pipe, inside and outside, would not permit of later economical protection.

Routine filter operation includes weekly flushing of the distribution laterals by removal of the 456 end nozzles; weekly flushing of the main distributors by opening a 6-inch valve located at the inlet end of each distributor. The siphon discharge of the influent tends to stir the sediment and much of it passes through these valves into the main drains. Nozzle cleaning is a daily task and during the past nine years has average from 10.2 to 19.3 nozzles per acre per day, an all-time average of 15.3.

Resting of a filter has not been practiced; pooling occurs only during a few weeks in the early spring and usually disappears without attention. A serious filter pooling has occurred recently from growth which appeared in certain sewers and furnished seeding for the filter surface. A spike-tooth harrow, loaded with some 600 pounds of human weight and drawn by a Cletrac tractor, has greatly improved the conditions and it is hoped that no serious difficulties will occur next winter.

Ice formation on the filters has been present during the winter seasons. In prolonged zero or sub-zero weather it is the practice to re-

move the end nozzles to prevent damage to the distribution laterals. Generally, this is done only once or twice, for but a few days during a winter. The past three winters have been exceptional for protracted and extreme low temperature periods.

The trickling filters have a characteristic odor. No complaints have been received concerning odors from the filters, in fact, there has been but one odor complaint during the eleven years of operation. This was due to secondary tank sludge digesting on a drying bed. Odor has been noticed after a filter has been cut out of operation for a few days. Odor of industrial waste liquors has been noticed at the filters; the particular offender being tannery lime wastes, which had a burned flesh odor.

While the plant has been very fortunate in freedom from odor complaints it is not without odor by any means. This is true at night, rather than day. Since operation of the plant began, a sizeable community of homes has been constructed on a side-hill to the east of the plant and a main Boston-New York highway has been constructed so that it passes close to three sides of the plant and within 200 to 250 feet of the trickling filters.

Presentation of the results of filter operation involves a number of conditions which overlap, but it is believed that the manner of presenting them will emphasize the important facts.

I. Normal sewage—including industrial waste liquors.

Rate of filter operation: 1.5 mil. gal. per acre per day.

The combined nitrate and nitrite nitrogen content of the filter effluent averaged, from May to Sept. 1928, 5 to 9 p.p.m.; from May to Sept. 1929, 5 to 10 p.p.m. The dissolved oxygen content during these periods was: 1928, 5 to 6 p.p.m.; 1929, 5 to 7 p.p.m.

The stability tests during January, February and one-half of March varied from 75 to 80 per cent and during the other nine and one-half months the filter effluent was perfectly stable.

These are the usual results which may be expected from 10-ft. filters, 1½ to 3-inch stone, treating Imhoff tank effluent from Worcester sewage which contains pickling liquors, dye wastes, tannery and slaughterhouse liquors.

II. Industrial depression with decreased quantity of industrial waste liquors in the sewage.

Rate of filter operation: 1.20 to 1.35 m.g.a.d.

The decreased rate of filter operation (13.68 acres) indicates a decrease of 3.5 million gallons daily of industrial waste liquors. Owing to the fact that one-third of the sewerage system is on the combined plan, the above data appear more accurate than any estimation based on water consumption and sewage flow.

The combined nitrate and nitrite nitrogen from May to September, 1930, averaged 7 to 10 p.p.m.; 1931, 8 to 11 p.p.m.; 1932, 12 to 15 p.p.m. and 1933, 7 to 10 p.p.m. The latter figures include the first period of filter flooding for fly control. The dissolved oxygen contents during

these periods were: 1930, 5 to 7 p.p.m.; 1931, 6 to 7 p.p.m.; 1932, 7 to 8 p.p.m. and 1933, 6 to 7 p.p.m.

From April, 1930, until January, 1934, when the first abnormally cold winter set in, the filter effluent was perfectly stable throughout the entire year.

These results may be expected from the Worcester filters when the character of the sewage is primarily domestic. It is very evident that the presence of industrial waste liquors in normal quantities in the sewage slightly affects the dissolved oxygen content and causes a marked decrease of the nitrate and nitrite nitrogen content of the filter effluent. It is also apparent that the industrial waste liquors in the sewage result in the decreased stability of the filter effluent during ten weeks of the winter.

There are no results in either period of operation to suggest that the four weeks of spring pooling or the filter unloading affect the general results of filter operation or the stability of the effluent, which is 100 per cent as early as the middle of March.

Filter flooding for fly control will be considered, but it is of particular interest to note that while filter flies had been present in previous years, the first complaint occurred in 1932 when treating "depression" sewage and the first filter flooding was done in 1933. While no conclusion is justified until a return to normal sewage results in abandonment of filter flooding for fly control, it is pertinent to state that the change of character of the sewage may have been a contributing factor to excessive fly propagation. The change in character of the filter influent was not so much a change of average pH as of the decreased number and intensity of "doses" of industrial waste liquors in the sewage and their effect upon the character of the filter influent.

Winter operation of trickling filters produces inferior effluents. Abnormal winter temperatures prevailed during the winters of 1933–34 and 1934–35 and to some extent, during the past winter. The effect of these conditions upon the quality of the filter effluent is very well shown in the change of the stability results and the delayed recovery of the filter. Data concerning atmospheric temperatures and filter effluent stability results are presented in Table I.

During the winter of 1933–34, Dec. 29 and 30 were extremely cold; January temperatures were about normal. During this period only two samples of filter effluent tested did not prove to be stable. In February there were extremely low temperatures. The result was a large drop in the stability figure of the filter effluent. Temperature conditions during March were not especially severe, but the filter recovery was very slow. The average stability results include, April, 78 per cent; May, 86 per cent and June, 99 per cent. Some 99 + per cent results were obtained during May and perfect stability of the effluent, May 25th. Stability tests are made fourteen days at 20° C. as 99 + per cent and perfect stability is interpreted as continued 99 + per cent stability.

During the winter of 1934–35, the last nine days of January were extremely cold, including February 1st, with a minimum temperature of —13° F. Throughout this period there were from 15 to 17 inches of snow on the ground. The filter effluent stability dropped to 75 to 80 per cent, then with a steady trend toward warmer weather, the stability results immediately improved, the effluent being perfectly stable from Feb. 6th until the end of the month. Perfect stability of the filter effluent commenced about April 10th.

The past winter is interesting in that from Jan. 24 to Feb. 15, a period of 23 days, the maximum air temperature reached 33° F. on but one day. There were but five days when the minimum temperature

TABLE I.—*Winter Atmosphere Temperatures and Per Cent Relative Stability of Trickling Filter Effluent*

Month	Temperature of Atmosphere					Per Cent Rel. Stab. Average
	Average			Extreme		
	Max.	Min.	Mean	Max.	Min.	
1934						
Dec. (1933)	33.8	16.9	25.4	49	*—19*	99+
Jan.	35.7	20.5	28.1	54	— 5	99—
Feb.	26.6	*4.0*	*15.3*	49	*—20*	55
Mar.	45.1	24.6	34.9	65	5	65
1935						
Dec. (1934)	33.5	18.7	26.1	63	1	99+
Jan.	29.7	*10.0*	19.9	59	*—19*	91+
Feb.	35.4	*15.1*	*25.3*	49	*—13*	95+
Mar.	48.0	27.9	37.9	68	1	92+
1936						
Dec. (1935)	30.8	18.5	24.7	50	— 2	99+
Jan.	31.6	16.8	24.2	54	— 5	79
Feb.	27.9	10.6	19.2	48	— 3	63
Mar.	51.8	33.7	42.7	68	7	82

was above 10° F. The poorer stability results commenced the middle of January and continued until the middle of March, thereafter perfect stability of the filter effluent prevailed. These data are representative of a normal winter, and the sewage was normal, but the stability results of the effluent were lower.

During the past two winters, the recovery of perfect stability of the filter effluent has taken place prior to spring pooling of the filter surface and unloading of the filter. The delayed recovery of the first winter is difficult to explain when we consider the data that have been presented and recall that filter flooding was also practiced in 1934 and 1935. However, it is true that while low temperatures may necessitate protection of the distribution system, unless included in an extended

period of low temperature, there should be no serious effect upon the stability of the filter effluent.

The occurrence of the filter fly at the Worcester plant is interesting for the reason that while flies were bothersome at times, conditions were not bad until June, 1932, when the first complaint was received from neighbors. Personal investigations were made and owing to the considerable amount of work involved in preparations for filter flooding, we were able to delay the work until the following year. The first complaint in 1933 was on May 22nd and on the next day conditions were so bad that netting was procured for the men to use.

Flooding was practiced from May 29 to Sept. 2, 1933, following a week of rush work in fitting plank dams, wedges, raising manholes and sandbagging 800 feet of center wall. The beds were drained through molasses gates placed in the lower section of the plank dam. The arrangement was crude, slow to handle and the filters drained very slowly. Late in September, the center wall was raised with eight inches of concrete.

During 1933 and from May 23 to Aug. 14, 1934, the frequency of flooding was determined by doing as little as possible if there were no complaints concerning flies. The interval between floodings averaged from 10 to 12 days. Mention has been made of the decreased quantities of nitrate and nitrite nitrogen and of dissolved oxygen, May to Sept. 1933, as compared with prior summers. The effluent, however, was perfectly stable.

Following the first cold winter with delayed filter recovery, the flooding period of 1934 was accompanied by a drop in the nitrate and nitrite nitrogen content of the effluent, compared with 1933, from 7 to 10 p.p.m. to 2 to 7 p.p.m. and of dissolved oxygen, from 6 to 7 p.p.m. to 2.5 to 6.5 p.p.m. Despite the cold winter, spring pooling, filter unloading and a strong influent, a perfectly stable effluent was obtained May 25th and stability continued throughout the flooding period.

During April, 1935, gates were installed in place of the plank dams at the east end of the dry and wet (drain) filter galleries, which greatly facilitated filter flooding. The flooding period was from May 13 to Sept. 12, 1935, starting with a ten-day and cutting to an eight-day cycle during the last month. The nitrate and nitrite nitrogen and dissolved oxygen contents of the filter effluent during the flooding season increased, compared with those of 1934, to 8 to 9 p.p.m. and 5 to 7 p.p.m., respectively. The effluent was perfectly stable throughout the entire season. It is true that these figures are lower than those of 1932, previous to flooding, but they indicate that if the filters are producing a good effluent prior to the flooding season, they should continue to do so if the sewage is not too heavily loaded with industrial waste liquors. The effect of the latter can not be determined until normal industrial conditions return.

Filter fly control by flooding as practiced during 1933–34 and '35 was a success in holding down the number of flies. The intent of the 1936 program was not to exterminate the fly, which, however, did occur,

but to place the flooding upon definite days of a weekly interval for the convenience of operating. The flooding season was from May 11 to Sept. 9, 1936. While but three samples of effluent in July and August were not stable, the best filter effluent was obtained in June and during the remainder of the flooding season, the nitrate and nitrite nitrogen and dissolved oxygen contents of the effluent decreased from 6.9 and 6.2 p.p.m. to 2.5 and 3.2 p.p.m., respectively. During the past month there has been a slight improvement.

There was some increase in the amount of industrial waste liquors in the sewage which might prove a possible factor, yet it is considered that the frequency of flooding was such that the filters had insufficient opportunity to maintain the filtering media in efficient condition. The fly can be exterminated completely, but in so doing, it is possible to carry filter flooding so far as needlessly to produce deterioration of quality of the filter effluent.

The writer has advocated the use of trickling filters of reasonable unit size as an advantage when it is anticipated that fly control by filter flooding may be practiced. The Worcester filter area of 13.68 acres is in but two units for purposes of flooding; therefore the entire flow for about 28 hours must be treated on 6.84 acres. The result is a marked decrease of the nitrate and nitrite nitrogen content and a decided decrease of dissolved oxygen content of the filter effluent. Upon decreasing the rate of operation, the nitrates and dissolved oxygen increased during the latter part of the day. Similar tests of the drainings of a flooded filter showed practically "zero" content. The same area divided into double the number of units for flooding purposes would mean a smaller proportion of "zero" effluent and the three units in operation would produce an effluent of better quality.

No difficulties of filter operation have been ecountered due to the iron content of the influent. Eleven years of operation have demonstrated that the Worcester trickling filters are capable of producing a satisfactory effluent under unusual operating conditions. In the presence of decreased quantities of industrial waste liquors in the sewage, filter effluent of better quality can be produced.

Mr. John H. Brooks, Jr., is Superintendent of Sewers of Worcester, Mass. The writer is Supervising Chemist of the Department, in immediate charge of operation of the sewage treatment plant.

Harbor Pollution

WASTES DISPOSAL AS RELATED TO SHELLFISH *

By Arthur P. Miller

Sanitary Engineer, U. S. Public Health Service, New York, N. Y.

Wastes, as used herein, means normal, domestic sewage free of excessive quantities of materials rejected by specific trades, and certain other industrial ones occasionally found in tidal waters. The term shellfish includes only oysters, and hard and soft clams.

Shellfish Can Cause Sickness

The biological mechanism of each of these three separate kinds of shellfish will not be discussed at great length. Probably it is needless to explain that these bivalves obtain their sustenance from the waters overlying their beds. Large quantities of water (25 to 50 gallons per day for the oyster) are involved in their eating processes but they are so constituted that sufficient food can be secured under normal conditions to maintain life and produce growth. Having stomachs and intestines we know that the foods taken in by them must go to the stomach and that the material which they reject must pass out through the intestines. Consequently, if a bivalve is caught at a moment when its stomach or intestines contains matter useful to them but inimical to humans and is then eaten raw, there has been a transfer of those dangerous matters to the stomach of the consumer. The result may be adverse to the consumer.

We know, also, that outside the bivalve itself but within its shell there exists a small quantity of "liquor" which, similarly, may be a vehicle for organisms of a pathogenic character. When eaten raw a considerable portion of this liquor is consumed by the eater.

From the public health viewpoint, it is unfortunate that those who most enjoy shellfish as a food seem to love them best in the raw state, for in this state they are most likely to cause sickness if they contain substances or organisms which the consumer's system can not resist.

Not only in the raw state can oysters, at least, produce serious consequences in the eaters. Hunter and Harrison[1] in their bacteriological and chemical study of oysters, state that "from the information at hand it is apparent that no reliance can be placed upon the ordinary cooking processes to sterilize oysters and render those which might possibly contain pathogenic bacteria, safe for consumption." Lumsden, *et al.*[2] state in Supplement No. 50 to the Public Health Reports

* Presented before the Spring Meeting of the New England Sewage Works Association, Providence, Rhode Island, April 26, 1937.

that "there is no reasonable cause for any popular apprehension that shellfish . . . which are heated throughout to a temperature of 100° C. before being eaten, are not as safe and salutary for human consumption as usual."

Without further evidence, this line of reasoning leads us to conclude that shellfish from polluted areas when eaten raw, and even when prepared for eating by a cooking process involving moderately high temperatures, must be suspected of the ability to carry diseases.

Disease Outbreaks

This conclusion is adequately supported by proof that shellfish, in the past, have caused serious epidemic and endemic outbreaks of disease. In the Report of the Committee on Shellfish of the American Public Health Association,[3] Fisher cites 52 epidemics occurring from 1815 to 1936 in this and foreign countries in which cases of typhoid fever, cholera and gastro-enteritis were ascribed to contaminated shellfish after rather careful investigations. In a second appendix, he and his fellow committee members have listed 64 endemics which include sporadic cases occurring in the general population over a rather long time interval, usually about a year.

The report[2] of the investigation of the typhoid fever epidemics of 1924 and 1925 in Washington, New York and Chicago, is a classic on this subject. The first conclusion of that study was that "the main factor in the spread of the infection . . . was beyond reasonable doubt shell oysters. . . ." Fisher, in his citation of epidemics heretofore mentioned, indicates that 310 cases of typhoid fever were involved in these three outbreaks.

In New York City, for the 11-year period 1924 to 1934, of 8810 cases of typhoid fever, 1012, or 11.4 per cent, were attributed to contaminated shellfish.

Pollution Forces Certain Procedures

These few references give ample proof—if that be needed—that there is considerable danger to the health of the public if shellfish for marketing are drawn from water areas in which wastes are disposed in excessive amounts. There can be no doubt that public health authorities are amply justified in strenuously objecting to the sale of any shellfish which come from any water area suspected of being polluted to a serious degree. This has been the policy of health agencies for many years and will certainly continue to be so with the very definite possibility of even more rigid and careful attention being given to sources of supply if the quantities of wastes now being discharged into tidal waters are not curtailed. The pollution of shellfish growing areas and the corollary need for excluding unsafe shellfish from the markets have brought into being several procedures involving the industry, some of which are applied by health authorities and others by the industry itself. These may be described briefly as follows:

1 Closing entirely highly polluted areas;
2 Restricting the use of moderately polluted areas;
3 Relaying shellfish from moderately polluted areas for self-cleansing purposes;
4 Providing artificial basins for self-cleansing purposes.

Prior to 1925, control of the quality of market shellfish rested entirely with the selected agencies in each state. As might be expected, some states performed creditable work and others did not. Those in which shellfishing was an important industry, and a favorable revenue was produced for the state, spent fair sums on their investigatory and control work. However, there is no gainsaying that in certain sections control was lax, if not non-existent. There was but little unanimity of opinion as to procedures and, aside from bacteriological examination methods, almost no standardization. States in the interior of the country were at the mercy of the producing states as to shellfish quality and had to accept what was shipped or do without.

Public Health Service Activities

The 1924–1925 epidemic of typhoid fever was so severe and widespread that public confidence in shellfish, particularly oysters, was badly shaken. Because of this, the oyster growers urged that health officials take some action to restore the confidence of the public in the safety of shellfish as a food product. A meeting of health officials and representatives of the industry was held in Washington in 1925 and out of that grew a committee appointed by the Surgeon General of the Public Health Service to formulate recommendations for the sanitary control of the shellfish industry in the United States. This committee presented a report in September, 1925, which has been used since that time as a basis for all work done by the Public Health Service in this field. The portion of that report [4] which is particularly applicable to this discussion is as follows:

> That only those (shellfish) should be marketed which have come from beds which, on careful examination, are found to be free from any justifiable suspicion of dangerous contamination with disease-producing micro-organisms and free from such other contamination as might be deleterious or offensive.

In addition to the appointment of the committee which prepared the above-mentioned report, the Public Health Service was asked to take an active part in shellfish sanitation work by continuing to serve as a coordinating and checking agency in order that the interior states, as well as those which produce shellfish, might be assured that the product shipped in interstate commerce was of satisfactory quality. Through a system of certification, the Public Health Service has been able to bring about increased activity in this field in many states and to influence the procedures in those states where previous work had not been particularly effective.

One of the first problems to be approached by the Service had to do with the sanitary quality of the growing areas. Many studies were

made, both by Service personnel and by personnel of the States in collaboration with Service personnel. After several years' intensive work the status of all important areas was generally determined and the industry settled down to a more remunerative existence.

Frequency of Area Study

There is a tendency in some states to consider initial surveys of shellfish areas sufficient for all time. It is believed that that position is untenable. Wastes are being discharged into tidal waters all the time and their contributing populations are increasing in most instances. Tidal currents are at work changing bottom and shore line contours, often realigning the direction of flow of large bodies of discharged wastes. Therefore, it is not deemed safe to assume that one can study a questionable area, divide the good from the bad, and then take for granted that that imaginary division line will never shift. It is my opinion that surveys and studies of shellfish producing areas should be made periodically. Where there has been an opportunity to inaugurate work of this kind, it has been recommended that it be planned so that each area, or at least all portions of areas in a border-line classification, can be studied once in every three years. This policy is not always accepted but it is still urged as one which should not be ignored. One state exceeds this general policy and annually studies all of the border-line portions of all of its producing areas. This method has the decided advantage that work of this kind can then be made a part of an annual routine and does not have to be set up as a special problem each time it is found necessary.

Areas Closed

Area studies come to our attention each year. Only recently work was done in the Rhode Island portion of Mount Hope Bay which indicated that all of that Bay should be closed to shellfishing and, subsequent to that action, that portion of the Bay in Massachusetts was closed by the Massachusetts authorities. There seems to be no doubt but what these closures were made necessary at this time by increasing volumes of sewage and their further encroachment on areas once safe. To those whose livelihood depends upon fishing in home waters, the closing of Mount Hope Bay presents a definite hardship. Also, the territory surrounding this section will be deprived of the income which might have accrued to it through the activities of its shellfishermen. Closing these sections adds to the burdens of the State agencies which are charged with keeping them closed. In this particular instance, a solution lies in the treatment of sewage now reaching Mount Hope Bay to such an extent that the waters will not receive more wastes than they can readily assimilate without danger to the bivalves growing there.

Raritan Bay Study

Not always does a study of an area bring about further restrictions. In December, 1924, New York city closed its markets to shell clams

from Raritan Bay, New Jersey. This was a serious blow to the clam industry in that portion of New Jersey bordering on the bay. In 1935, 11 years later, an agreement was reached between the New Jersey and the New York City health authorities and the Public Health Service to restudy this area with the understanding that New York City would revise its decision in case the results warranted it. This study has been described by the writer in other places[5] but, as it serves as an example of how such an investigation is made when under the auspices of the Public Health Service, a brief resume of it will be given.

In planning the work in Raritan Bay, there seemed to be three major points which required consideration:

1 The quantities of raw and treated sewage reaching the Bay;
2 The influence of natural agencies such as winds, tidal currents and channels on the movement of the sewage;
3 Bacteriological confirmation of tentative decisions reached after examination of the physical data.

Rough estimates of the amount of sewage reaching these waters in an untreated state indicated 858 m.g.d. of which 844 m.g.d. entered through the Narrows. Because of the immense volume of sewage entering at this point, it was considered of critical importance; the remaining sewage reached the Bay in such small volumes and at so many points that it could be fairly well assimilated. Attention, therefore, was directed primarily to the flow through the Narrows.

From the 1914 report of the Metropolitan Sewage Commission, it was ascertained that the volume of diluting water at the Narrows was of such proportions that this quantity of sewage represented only about 0.84 per cent of it or, expressed in other terms, there were about 119 gallons of diluting water for each gallon of sewage. This fact carried considerable weight in the summation of the relation of raw sewage contributions to the quality of the overlying waters and was stressed in this conclusion:

> We find fairly adequate dilution available for those wastes not directly deposited in the Bay; 1.1 m.g.d. discharged immediately into the Bay on the New York side; and 44 m.g.d. deposited at a point on the same side sufficiently close to Bay waters to have an effect on them because of tidal currents. Although this Bay occupies an unfortunate position for shellfish cultivation on account of the metropolitan character of the surrounding territory, the great volume of water in it seems to afford fair protection to certain selected areas. If only a small portion of these wastes were in direct contact with the shellfish areas under consideration there would have been little purpose in this study but dilution and other factors to be discussed force one to entertain more favorable conclusions regarding their quality.

The major channels in this large body of water were taken into consideration, too. Without giving thought to this physical factor, one might assume that the tremendous volume of sewage (844 m.g.d.) entering the Bay through the Narrows would mix thoroughly with a large proportion of the Bay waters. There was found to be without doubt some intermingling of sewage and relatively clean water at the edges of this flow, but on the whole it was seen to follow a fairly well-

defined path. One of the forces which tended to control these wastes and keep them to a well-defined section was Ambrose Channel, which carries New York Harbor traffic out to sea. At the other end of the Bay, the wastes entering from Arthur Kill were influenced by a 30-foot channel which, fortunately for the quality of the New Jersey waters, runs from the tip of Staten Island up into Princess Bay on the New York side and then off toward Sandy Hook.

Tidal currents and winds are two other variables which may influence the results of a study of any body of water having great width. Accurate tidal information on Raritan Bay was available in U. S. Coast and Geodetic Survey publications and definite conclusions as to the movements of tidal waters and sewage could be charted. Briefly, it can be said that tidal flows were such as to help restrict the large quantity of New York sewage to New York waters thereby protecting those on the New Jersey side. These conclusions were generally supported by float studies made in 1914 by the Metropolitan Sewerage Commission.

The one physical factor which might have worked quite adversely to the quality of the New Jersey waters was the winds. Averages over a long time period indicated these to be from the direction most favorable to forcing sewage into New Jersey waters. However, the average wind strength was only a moderate breeze and, consequently, its average effect could not be very severe. The direction of these winds had more to do with the final decision to close an additional area off Sandy Hook than any other factor.

Our final step in this study was bacteriological work. A large volume of water samples over the entire area were so collected that complete series were had at five different tides. The results of the tests of these samples were compared with the unwritten standard in use by the Public Health Service to the effect that not more than 50 per cent of the one cubic centimeter tubes in an area should show the presence of B. coli if that area is to be used for the taking of market shellfish.

Based on all of these elements (sewage volumes, channels, tides, winds and bacteriological results), there was added to the areas closed many years before in New Jersey Raritan Bay, a triangular piece near the outer end of the Bay. Although this small section increased the total closed area, the study was so conducted that all agencies were satisfied and the New York City market was again opened to shellfish from that large portion of the Bay which it was unnecessary to restrict.

All of the areas which I have mentioned above were unquestionably polluted by disposal of wastes to such a point as to make them unsafe for the removal of market shellfish. Their only chance of being reclaimed so as to be useful again for market shellfish production is through a reduction of the amount of raw sewage and other wastes going into the tidal waters in question.

Intermittent Restriction

Some states have set up what might be called a two-way policy with regard to closing and restricting shellfish areas. Those which are fouled by sewage are kept closed constantly. Others are permitted to be used when certain sewage processes are in operation and particular water temperatures exist. For example, at Norwalk, Connecticut, an area inside of Norwalk Islands is closed for about nine months of the year but when the Norwalk sewage treatment plant is operating satisfactorily and the water temperature is below 41° F., the area is considered to be open. Usually, this temperature condition is fulfilled during three cold months of the winter.

In another area near Norwalk, shellfish beds are open during seven winter months but closed from May 1st to October 1st because of the increase of sewage contributed by summer residents contiguous to the water. Off Highlands, New Jersey, there is a section which is closed from May 15 to October 15 for the same reason—too much untreated sewage in the waters during the summer resort season.

This method of intermittently restricting operations can be effective if it is applied after careful studies have been made and with judgment. However, it has a weakness, in that it is dependent upon physical factors which, if they do not function as planned may entirely upset one's calculations. A sewage treatment plant ordinarily is expected to work correctly but there is no reason why it may not fail when least expected. Hence, precaution and judgment should be paramount in applying a plan of intermittent restriction.

Re-laying Shellfish

The need for closing areas where shellfish are growing to those fishing for market purposes is far easier to support scientifically than it is on an economic basis. Those whose normal working area is reduced by a closure are seldom satisfied that the proper decision has been made. It behooves all supervising authorities, therefore, to make every effort to release for use those shellfish which would otherwise be left untouched in polluted waters.

In drafting the Public Health Service Minimum Requirements, which were based on the report of the committee heretofore discussed, this point was recognized by making provisions for relaying shellfish from seriously polluted beds into clean waters, in the following language:[2]

> No shellfish shall be taken from any water except from such grounds or growing areas as have been approved by the State agency having jurisdiction over shellfish sanitation. Such approval by the State agency must be based on the recommendations made by the Committee on Sanitary Control of the Shellfish Industry.
>
> Provided, that the removal of shellfish from areas not approved by the State agency having jurisdiction over shellfish sanitation shall be permitted for the purpose of relaying in approved waters only during the closed season for marketing and not less than 15 days prior to the opening of the next market season.
>
> Provided further, that permission may be granted by the State agency having jurisdiction over shellfish sanitation for the removal of shellfish from unapproved areas

during the open season and to market them after relaying in a large body of clean water, but only under the following conditions:

(*a*) That such permission be granted only to individuals known to be entirely responsible and trustworthy, and only under special permit. (It is recommended that such individuals be bonded, the bond to be forfeited in case of any violation of the conditions of the permit.)

(*b*) That such special permit shall be issued only for removal from privately owned or leased beds.

(*c*) That the shellfish be relaid in a designated area of clean water (Class 2 as defined by the Committee) for a minimum period of 30 days when the water in which relaid has a temperature between 50 and 60° F., and a minimum period of 15 days when the water has a temperature of 60 degrees F., or greater. When the temperature of the water in the class 2 area is below 50 degrees F., transplantation for marketing purposes will not be permitted.

(*d*) That the removal and relaying shall be under the immediate and constant supervision of a representative of the State agency having jurisdiction over shellfish sanitation.

(*e*) That subsequent removal from the clean area, for sale or shipment, shall be made only under special permit granted by the State agency having jurisdiction over shellfish sanitation.

Among others, the Commission of Fisheries of the State of Virginia has established workable regulations covering transplantation activities. These are contained in a section of the pamphlet entitled "Laws of Virginia Relating to Fisheries of Tidal Waters."[6] Practically, the Virginia plan works only if the two departments involved cooperate closely with one another. A permit issued by the Commission of Fisheries to remove from a polluted area should become operative only under adequate observation and, in some cases, bond. When transplanted shellfish are re-laid for cleansing purposes, they then come under the purview of the State Department of Health and can be removed for marketing only if the temperature requirements have been fulfilled and a certificate permitting such removal is issued. If the agency issuing the original removal permit does not keep the one issuing the secondary removal permit informed regarding its actions, there is a lapse in the procedure which permits practices dangerous to the consuming public.

Relaying from polluted areas to clean ones is a plan which should be encouraged. So often, it seems, some of the best growing grounds are in sections which must be closed because they receive excessive discharges of raw wastes. To fail to remove these shellfish to areas in which self-cleansing can take place is to neglect a source of revenue which is worth conserving. The ideal plan under which transplantation should take place is that which involves only the State supervising agency. Then there can arise no question of jurisdiction or of the possibility of contaminated shellfish short-circuiting the cleansing process and reaching the market directly. If this can not be done by the State, experience shows that private authorities can satisfactorily perform this function if they are responsible operators and are required to work under such regulations and observations as the situation seems to demand.

Relaying for cleansing purposes has not been practiced as generally as it should. It offers one means of side-stepping the harm done by unbridled pollution of growing areas and should be more often employed.

Artificial Cleansing

The fourth result of uncontrolled waste discharges into tidal shellfish-bearing waters has been the provision of artificial cleansing processes. According to Fisher,[3] the first shellfish cleansing plant in which shellfish were handled commercially was constructed at Conway, England, in 1916, to cleanse mussels. This same year some experimental work along this line was done at Jamaica Bay, New York and New Haven Harbor, Connecticut.

Wells[7] conducted some work of this character at the Fisherman's Island laboratory and concluded as a result of it "that oysters which have lain in polluted water can be artificially purified to such a degree as to pass a most rigid standard by exposure for a short period in water containing calcium hypochlorite. . . ."

Carmelia[8] also has reported on the purification of oysters by the use of hypochlorite. This work was done in Great Kills Harbor on Raritan Bay and some of the conclusions were as follows: "In oysters scoring in the neighborhood of 50 or more, an average reduction of 90 per cent of the *B. coli* content can be confidently expected. . . . It is believed that oysters with an original score of 230–320 represent about the maximum pollution which can be safely reduced to an acceptable score and yet provide the desired factor of safety."

In America, the first commercial shellfish cleansing plant was built at Inwood, Long Island, New York about 1921 to treat oysters and continued in operation until 1925. At the present time there are two cleansing plants in operation in Massachusetts for soft clams. The areas from which these clams may be taken are of a border-line classification and are determined by the Massachusetts State Department of Public Health. Likewise, the degree of treatment which they must receive before being released for the market and all other matters pertaining to their processing are governed by regulations of that department. Wright[9] has described one of these plants and has given the regulations under which they are operated. Insofar as is known, the cleansing of soft clams as carried on in Massachusetts has been successful and has demonstrated the practicability of the process when the clams come from areas not too seriously polluted.

Virginia has recently constructed an experimental plant at Willoughby Beach, Virginia, to study further the feasibility of artificial cleansing of oysters. In a few other places cleansing takes place in artificial containers but this is incidental to the primary purpose of conditioning shellfish from normally clean beds to enhance their shipping qualities.

Specific Wastes and Oil

So far this discussion has related almost entirely to sewage. What of the other more specific wastes commonly discharged by industrial

plants? Shellfish depend largely for their food upon substances washed down into the bays and estuaries by the rivers. Therefore, any waste substance which adversely affects the food supply of shellfish has a stunting or killing effect on them. Certain industrial wastes and chemicals (as well as sewage) affect the acidity of the receiving waters. "Aquatic forms, especially the microscopic ones, are highly sensitive to these changes and even small variations in the acidity may mean destruction or diminution of species."[10] Ionized metals, especially the heavy ones like copper and zinc, may also operate to destroy aquatic life.

Without regard to food supply, certain wastes are deleterious to shellfish at various stages of growth. Churchill[11] found that with sulphuric acid in a 0.01 per cent solution, 18 per cent mortality occurred in five days among spats (small oysters). He also tested various solutions of metallic salts (copper, lead and zinc) and dyes upon oyster larvae and spats and found them to have a high degree of toxicity. Even in small amounts they were a serious menace to the young oyster. These metals are not unusual in industrial waste discharges.

Oil and oil containing wastes are other substances which do no good to shellfish. Speer,[12] in discussing this question, brings out the following points: The oyster larvae spends from 14 to 16 days swimming near the water surface and a film of oil there will kill larvae within a few hours. Heavier portions of oil settle to the bottom and kill by direct contact. These wastes may also destroy the food supply by killing minute surface plants and animals thereby indirectly affecting larvae and larger forms. Still another serious effect of oil is its quality of imparting a disagreeable taste to market shellfish. This, of course, will cause a rejection of shipments and a loss to the unfortunate dealer.

Summary

It has been shown that shellfish reaches, in a direct way, the digestive system of man and that through that port of entry may cause disease if carrying pathogenic organisms. That such does occur has been supported by adequate evidence. Pollution of shellfish growing areas by both sewage and trade wastes has forced certain action by health authorities and the industry chief among which are the complete and partial restriction of areas and the provision of both natural and artificial means to permit self-cleansing. Specific trade wastes have both direct and indirect deleterious effects on bivalves.

Conclusion

Wastes disposal in tidal waters, if continued without due regard to the serious consequences on shellfish and the industry which they support can, therefore, not be considered justifiable. Most large bodies of water can be used for many purposes but to do so successfully there must be an adequate division of rights so that one use does not become so excessive as to totally exclude all other uses.

BIBLIOGRAPHY

1. A. C. Hunter and C. W. Harrison, "Bacteriology and Chemistry of Oysters with Special Reference to Regulatory Control of Production, Handling and Shipment," U. S. Department of Agriculture Technical Bulletin 64, March, 1928.
2. L. L. Lumsden, H. F. Hasseltine, J. P. Leake and M. V. Veldee, "A Typhoid Fever Epidemic Caused by Oyster-borne Infection," Supplement No. 50 to the Public Health Reports, 1925.
3. Report of the Committee on Shellfish of the American Public Health Association, American Public Health Association Year Book 1936–1937.
4. Report of Committee on Sanitary Control of the Shellfish Industry in the United States, Supplement No. 53 to the Public Health Reports, November 6, 1925.
5. Arthur P. Miller, "A Study of the Pollution of a Shellfish Growing Area," *This Journal*, **8**, July, 1936.
6. "Laws of Virginia Relating to Fisheries of Tidal Waters," The Commission of Fisheries, Newport News, Virginia, 1936.
7. W. F. Wells, "Artificial Purification of Oysters," Reprint No. 551 from the Public Health Reports, July 14, 1916.
8. F. A. Carmelia, "Hypochlorite Process of Oyster Purification," Reprint No. 652 from the Public Health Reports, April 22, 1921.
9. Edward Wright, "Shellfish Treatment Plant at Newburyport, Massachusetts," *American Journal of Public Health*, **23**, No. 3, March, 1933.
10. R. V. Truitt, "Oyster Problem Inquiry of Chesapeake Bay," Sixth Annual Report of the Maryland State Conservation Department, 1928.
11. J. S. Gutsell, "Oyster Cultural Problems of Connecticut," Bureau of Fisheries Document No. 960.
12. Carl Speer, Jr., "Sanitary Engineering Aspects of Shellfish Pollution," *Bulletin of the Maryland State Department of Health*, **1**, No. 3, April, 1928.

PROGRESS IN CONTROLLING POLLUTION OF RHODE ISLAND WATERS *

By Walter J. Shea

Chief, Div. of Purification of Waters, Rhode Island Dept. of Public Health

The numerous bills before the Congress at the present time providing for the participation of the Federal government in stream pollution control suggest a review of the progress made in Rhode Island in this field, through state anti-pollution legislation. The pollution problems in this state are sufficiently varied to make them representative and indicate how the Federal government may be of assistance in their solution.

Until 1920 Rhode Island law dealing with water pollution granted authority for its control in a very limited number of instances. The State Commissioners of Shellfisheries were authorized to prevent pollution of shellfish areas and the State Board of Health had authority to prevent the pollution of public water supplies. Chapter 125 of the General Laws enacted in 1920 created a Board of Purification of Waters, authorized and directed to regulate or prohibit the pollution of the waters of the state in accordance with its provisions. Pollution is held to mean the discharge of waste in such quantities as to cause or be likely to cause either by itself or in connection with other waste so discharged, damage to the public, or to any person having a right to use said waters for boating, fishing or other purposes, or owning property in, under or bordering upon the same. The act does not apply where the sole damage done is the rendering unsuitable for drinking purposes or ice supply of the waters so polluted. This legislation afforded a means of attacking the pollution problem on a broad front. The Administrative Code Act of 1935, reorganizing the state government, transferred the powers and duties of the Board of Purification of Waters to the Division of Purification of Waters in the Department of Public Health.

The menace of pollution to the rich shellfish grounds and excellent recreational facilities of Narragansett Bay was chiefly responsible for the public demand for anti-pollution legislation. All the rivers of the state, with the exception of two, eventually discharge into Narragansett Bay, carrying with them wastes received in passing through cities and towns. The wastes which create pollution problems may be classified as oily wastes, domestic sewage and manufacturing wastes. The last mentioned are produced largely by the textile industry.

Oil Pollution

Oil pollution, caused by the many oil-handling terminals located for the most part in the upper reaches of the Bay and in the Providence River, is far reaching and very damaging in its effects. The steps that

* Presented before the Spring Meeting of the New England Sewage Works Association, Providence, R. I., April 26, 1937.

can be taken to prevent damage from oil that has been spilled into the public waters are few and limited in application. A successful program for the control of oil pollution must be based upon the utilization of preventive measures at the potential sources of pollution.

Rules and Regulations were established by the Board of Purification of Waters to prevent the discharge of oil into the waters of the state. Copies of these are posted at prominent places on all oil-handling premises located near the public waters. On recommendation of the Board various practices were adopted and devices installed by the oil companies to prevent the spilling of oil into the public waters. Oil tankers discharging their cargo are required to have their scuppers plugged tightly and to place drip pans under disconnected hose unions. Pressure gauges in oil lines provide a method of checking excessive pressures. Among the preventive measures of a permanent nature adopted are, dikes around storage tanks, bulkheads to prevent seepage to the waters from oil soaked ground, caulked docks with raised edges, wooden conduits packed with sawdust for pipes running along docks, and oil separators for the removal of oil from liquid wastes.

Garage oil discharged to sewerage systems is usually well controlled by municipal authorities when the sewage is carried to a treatment works. Discharges of oily liquid wastes from gas manufacturing plants and industries burning fuel oil are important contributing sources. Oil separators and filters have been installed by gas manufacturing plants to remove oil from liquid wastes. A survey was made of manufacturing plants burning fuel oil and located near the public waters or having connections to sewer systems not served by treatment plants. Based upon the experience gained from oil spills occurring at these plants, recommendations were made relative to the disposal of drainage from oil burning equipment, and the proper point of discharge of lines carrying exhaust steam from oil heaters, pumps and storage tank coils. These were found to be the principal danger points.

The mere adoption of preventive measures will not guarantee that the public waters will be free of oil. Persistent inspection of oil handling places must be maintained.

The pumping of bilge water to the Bay from oil carrying ships has been a source of oil pollution very difficult to control. Ships calling regularly at Rhode Island ports are familiar with the rules and regulations prohibiting this practice, and are not offenders. Occasionally, however, an infrequent caller will pump her bilges on leaving, and it is seldom possible to fix responsibility with certainty. The policy of issuing a warning to all shipping lines having boats in the bay at the time of the discharge has been followed. Once during each of the last two years bilge water has been discharged into Rhode Island waters. In one instance it became necessary to lessen the draft of a ship which had gone aground, in the other, a new caller was responsible. No prosecutions for violations of the rules and regulations to prevent the discharge of oil to the public waters have ever been made. Without doubt, the fact that civil suits may arise from damage done by oil dis-

charged to the public waters, has been a deterrent to negligence on the part of oil companies, and has provided a basis for the excellent cooperation given the Division of Purification of Waters in preventing these discharges.

During 1936 nearly a billion gallons of petroleum were received at Rhode Island ports. Despite the potential menace that exists in transferring this enormous volume of oil to land terminals, there was only one discharge of oil to the public waters of any consequence and this did not cause serious damage. The menace of oil pollution to Rhode Island waters appears to be under control.

Sanitary Sewage and Industrial Waste Treatment

It is estimated that 63 per cent of the population of the state is served by sewerage systems. Eight municipal sewage treatment plants treat about 92.5 per cent of the sewage collected by these sewerage systems. When Chapter 125 of the General Laws relating to the control of pollution was enacted in 1920 only four of these eight plants were constructed. Since then two of the four plants in operation at that time have undergone major renovation to provide more adequate treatment of the sewage they receive. The construction of three municipal plants was in compliance with orders of the Board of Purification of Waters, directing the municipalities involved to adopt a system or means to prevent pollution. The remaining improvements were brought about through cooperative action. The total expenditures for intercepting sewers and treatment plants by municipalities since 1920 amounts to over two and a third million dollars.

In addition to systems for the treatment of industrial waste already established in 1920, seven of major importance have been constructed. Nearly all of these are for the treatment of textile waste. There have been numerous installations of systems for the treatment of sanitary sewage at manufacturing plants. Thirteen establishments producing oily wastes have adopted systems to prevent pollution. Three plants of considerable size for treatment of sewage from institutions have been constructed. Hundreds of outlets discharging sewage to the public waters from private residences have been eliminated.

A conservative estimate of expenditures for systems of all kinds to prevent the pollution of Rhode Island waters made since 1920 would be a figure well over three and a half million dollars.

Under construction at the present time are a plant to treat wool scouring and cloth washing wastes at a textile plant in the southern part of the state and a plant to treat the sewage of the State Institutions at Howard, Rhode Island. Systems for the treatment of cotton cloth dyeing and finishing wastes of two large textile plants in the state are now being designed.

As has been already pointed out, the principal contributions of trade wastes causing pollution of Rhode Island waters are made by the textile industry. The adoption of treatment facilities by this industry has not kept pace with the installation of sewage treatment works by munic-

ipalities, for numerous reasons. The methods of treatment that are applicable to these wastes are more limited in number and sometimes less successful than in the treatment of sanitary sewage. Agitation for municipal sewerage systems in localities where textile wastes are produced and could be taken in the sewerage system has caused manufacturers to make the reasonable request that they be allowed to await the outcome of this agitation. It appeared unwise during the depression years to insist on expenditures by industry which might cause further curtailment of activity and thereby increase the rolls of the unemployed.

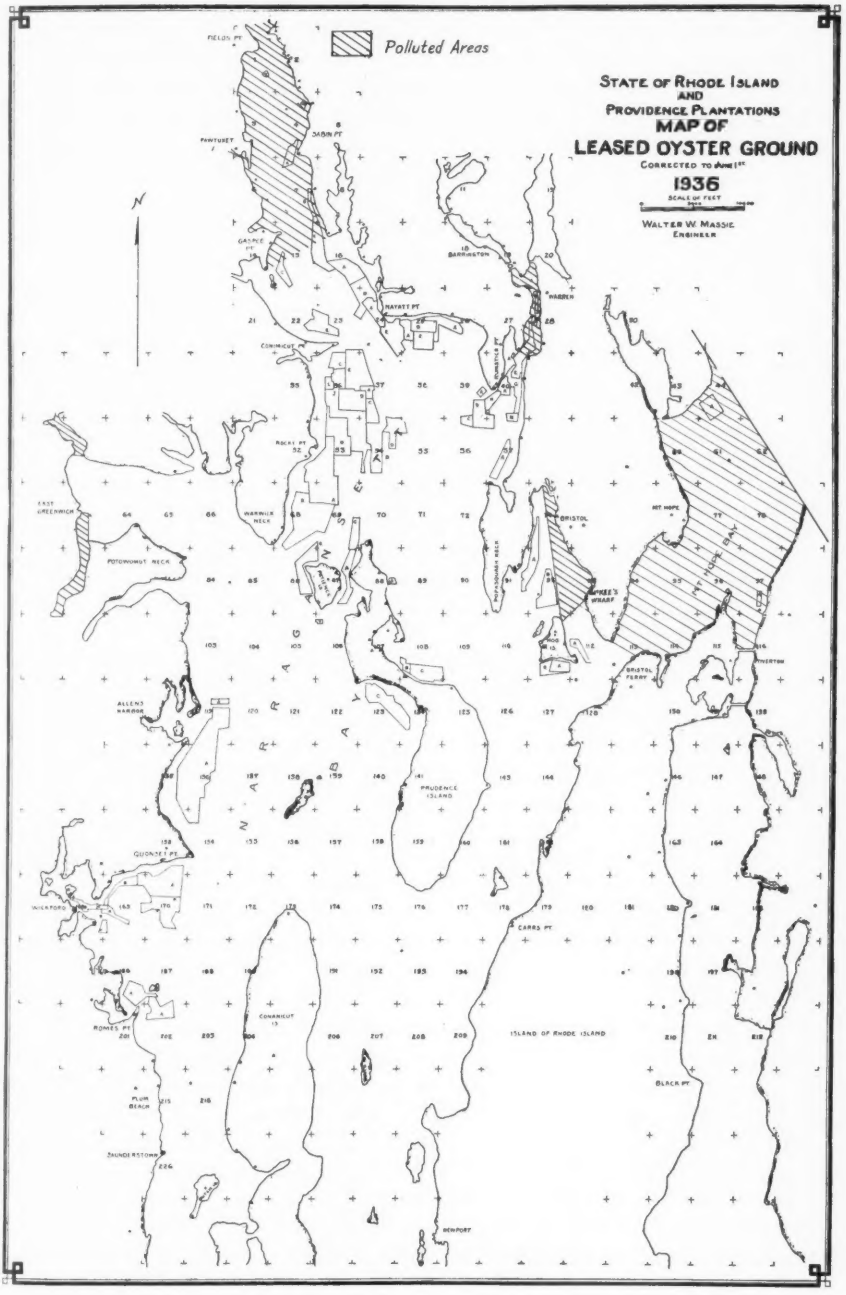
Reduction of the volume of dirty waters to be treated by the adoption of the counter-flow principle in wet processes where practicable, the utilization of available recovery systems, and separation of clean waste waters, are improvements which if taken within textile finishing plants will make treatment of these wastes less of a problem. The recent advances made in the use of the chemical precipitation method of waste treatment and the lowered cost and greater availability of chemicals, make this method of treatment appear to offer new possibilities for application to textile waste. The improved condition of the textile industry justifies demands for more speedy adoption of waste treatment systems.

Pollution of Shellfish Grounds

An estimate of the present condition of the waters of Narragansett Bay can be made by considering the area of the bay which is closed to the taking of shellfish for human consumption. The United States Public Health Service has arrived at the conclusion that waters used in the production of shellfish for the market should in general not show the presence of Coli-aerogenes organisms in 1 c.c. portions of samples more than fifty per cent of the time. Since much of the shellfish produced in Rhode Island is shipped out of the state, the Rhode Island Division of Fish and Game has adhered to this requirement consistently in passing upon the sanitary quality of shellfish producing areas. Tidal waters meeting this requirement then may be taken to be of good sanitary quality.

In the accompanying chart of Narragansett Bay the areas closed to the taking of shellfish for the market because of pollution are indicated. These include the Seekonk and Providence Rivers, Apponaug and Greenwich Coves, sections of the Warren and Barrington Rivers, Bristol Harbor, Upper Narragansett Bay and the whole Rhode Island portion of Mount Hope Bay. The total closed area is some 17.8 square miles or 11,383 acres. The total surface area of Narragansett Bay and its tidal estuaries is some 136.5 square miles or 87,373.4 acres. The closed area is about 13 per cent of this total.

On first thought one would be inclined to conclude that with 13 per cent of the large water area of Narragansett Bay still closed to shellfish production, the accomplishment of pollution control legisla-


Polluted Areas
STATE OF RHODE ISLAND
AND
PROVIDENCE PLANTATIONS
MAP OF
LEASED OYSTER GROUND
CORRECTED TO JUNE 1ST
1936
SCALE OF FEET
WALTER W. MASSIE
ENGINEER
N
NARRAGANSETT BAY
FIELDS PT.
PAWTUXET
GASPEE PT.
GREENWICH BAY
COMMUNICUT
HAYATT PT.
BARRINGTON
WARREN
BRISTOL
MT. HOPE
EAST GREENWICH
WARWICK NECK
POTOWOMUT NECK
ALLENS HARBOR
PROVIDENCE ISLAND
QUONSET PT.
WICKFORD
CARRS PT.
ISLAND OF RHODE ISLAND
BRISTOL FERRY
TIVERTON
BLACK PT.
ROMES PT.
PLUM BEACH
SAUNDERSTOWN
NEWPORT

tion in Rhode Island has not been considerable. It is necessary therefore to discuss some of the factors which bear upon this situation.

Following an investigation of the sanitary quality of the waters of Mount Hope Bay, the State Division of Fish and Game in December, 1936, saw fit to close this area to the taking of shellfish for human consumption. Pollution of this bay is caused by the discharge of untreated sewage and industrial wastes from communities in the State of Massachusetts, principally the city of Fall River. This action of the Division of Fish and Game more than doubled the total area of tidal waters in Rhode Island closed to the taking of shellfish. It would be unfair to the State of Massachusetts and the city of Fall River if it were not pointed out that the city has been passing through a period of financial stress, which made any large capital expenditures prohibitive. It is hoped that with business conditions rapidly improving, the city may be enabled with Federal assistance to go forward with plans for constructing a sewage treatment works which will restore Mount Hope Bay to a valuable shellfish growing and recreational area.

With this accomplished there would still remain some 6.2 per cent of the tidal waters of the state closed to shellfish production because of pollution of Rhode Island origin. Treatment of sewage now discharged to tributaries of Narragansett Bay in the raw state and improvement of some of the existing treatment works will reduce this percentage somewhat. There will be even then areas which it is difficult to foresee as being useful for the production of marketable shellfish. The upper portion of the Providence River, where much shipping is carried on, is exposed to the pollution which results from this activity. Areas near outlets from sewage treatment plants are certainly not aesthetically suited to shellfish production for the market, even though sewage treatment plants function efficiently all the time. The latter is a condition which still awaits attainment. Certain areas are subject to occasional pollution through the operation of storm overflows to sewerage systems constructed to receive storm water as well as sanitary sewage. A great deal of the sewerage in Rhode Island is constructed on this combined plan. It is doubtful if a satisfactory method of preventing these untreated discharges can be found, other than eliminating storm water from sanitary sewers. This remedy calls for a long drawn out, expensive, construction program. Because of the existence of these overflows investments made by municipalities in sewage treatment facilities often fail to produce all the beneficial results expected of them.

The area of oyster grounds leased by the state has fallen off from the peak figure of 20,846 acres in 1912 to 5,678.2 acres in 1936. This is a decrease of about seventy-three per cent. It should be noted, however, that of the 20,846 acres of grounds leased in 1912, only 2,438 acres or about 12 per cent of the ground was located in what are now closed areas. Failure of the oyster growers to obtain sets, and depredations of starfish are pointed out by the Commissioners of Shellfisheries as the principal causes for the startling decrease in the amount of leased oyster grounds.

Installation of municipal sewage treatment plants in recent years has caused the lifting of the pollution ban on some shellfish grounds. Far more important, however, is the fact that a vast amount of additional grounds would undoubtedly have been banned if these plants were not put in operation. Steady increases in sewage volumes through growth in population and sewer extensions would have advanced closure lines farther down Narragansett Bay.

Federal Participation in Stream Pollution Control

Impatience is felt in some quarters with the rate of progress in pollution control under state administration of anti-pollution laws. It was expected that in a short time all our waterways could be restored to pristine purity. The complexity of the problem, the enormous expenditures necessary to bring about the treatment of all wastes causing pollution, and the limitations of treatment methods are little realized. If administration of anti-pollution laws is to be carried out on a sound economic basis, the problem cannot be solved in haste. Even when formal proceedings under the law have been brought against recalcitrant offenders against the pollution statute years of delay have passed before the desired end was accomplished. It is doubtful that if mandatory authority were given a Federal agency for stream pollution control, accomplishment in this field would be speeded up.

The efforts of the Federal government in stream pollution control would be best directed in developing methods of treatment for wastes for which none are now reasonably available, improving upon existing treatment methods, and coordinating the work of state agencies, by bringing about interstate compacts for pollution abatement. Federal financial assistance to states, municipalities and individuals by means of loans and grants for waste treatment systems will do more to hasten their adoption than any other action that may be taken.

DISCUSSION

By Edward Wright

Sanitary Engineer, Massachusetts Department of Public Health

When it was first suggested that the writer discuss Mr. Shea's paper it was understood that the paper was to relate to the pollution of Mount Hope Bay, which is an interstate tidal estuary with an area of about nine square miles in Rhode Island and about five square miles in Massachusetts. It is noted that Mr. Shea, while discussing in an excellent manner the control of pollution of Rhode Island tidal waters, has indicated that the recent closure of the Rhode Island portion of Mount Hope Bay is caused by the discharge of untreated sewage and industrial wastes from municipalities in the State of Massachusetts, particularly the city of Fall River. The writer has every reason to sympathize with Mr. Shea and with the shellfishermen formerly operating in the closed portion of Mount Hope Bay, and he recognizes the pollu-

tion of the upper portion of the bay by Fall River sewage. Some obstacles are very difficult to overcome and the pollution of Mount Hope Bay is one of them.

In 1920 the Massachusetts Department of Public Health recommended legislation giving mandatory authority in the prevention of the pollution of the Taunton River, which is the main tributary of Mount Hope Bay, but this legislation was never adopted. When it first obtained authority to condemn shellfish areas one of the first areas condemned by the Department of Public Health was that portion of Mount Hope Bay in the vicinity of Fall River inside of a line drawn from the Tiverton, Rhode Island, boundary northerly to Brayton's Point in Somerset. This left a pie-shaped piece of the bay between the Rhode Island-Massachusetts boundary line and the line above described, which has an area of 2.7 square miles. While there was some feeling that this area was subject to pollution at times of heavy runoff, few shellfish were taken therefrom, and this area has always been considered a somewhat questionable one to be certified only after seasonal investigations.

Following the original findings of the Department, the U. S. Public Health Service, through its laboratory boat the "Shearwater," made a very thorough investigation of the pollution of Mount Hope Bay, assisted to a limited extent by representatives of the Department of Public Health. No report was ever filed with the Massachusetts Department of Public Health by the U. S. Public Health Service and conditions remained as determined in 1925 until this year. Under date of December 7, 1936, former Governor Green, now U. S. Senator Green, of Rhode Island, wrote to His Excellency, Governor Curley, stating that, with the recommendations of the U. S. Public Health Service, the Rhode Island authorities had condemned the Rhode Island portion of Mount Hope Bay for shellfishing, and requested mutual cooperation between the states. At that time samples were being collected in this area and an intensive investigation was made of the above described pie-shaped area, which showed that more than 50 per cent of the overlying sea water samples contained Coli-aerogenes in 1 c.c. portions. As a result of this investigation the Department determined that all of Mount Hope Bay in Massachusetts and the estuaries tributary thereto, with the exception of a small area of the Coles River north of the New Haven Railroad in Swansea, were unfit for the taking of shellfish. This disturbed a great number of people including those owning shore properties, and as recently as April 22 the Department notified the authorities of the town of Swansea that the waters of Mount Hope Bay adjacent thereto are satisfactory for public bathing, this recommendation being made after samples of the shore waters along the town showed that they compared favorably with those at popular bathing beaches along the Massachusetts coast line. The finding was also made with the knowledge that certain species of shellfish are known to consume upwards of 50 gallons of sea water per day and to harbor certain bacterial growths, while persons bathing in salt water ingest very little, if any, water.

In addition the Department has approved that portion of Mount Hope Bay west of the line drawn from the Tiverton, Rhode Island, boundary northerly to Brayton's Point in Somerset, for the taking of shellfish for purification purposes. Not over 50 per cent of the .1 c.c. samples of the overlying sea water in this area contained Coli-aerogenes, this standard being ten times the allowable Coli concentration of that generally acknowledged by shellfish authorities for overlying sea water for areas from which shellfish may safely be taken for direct use as food.

Coming back to the question of relieving Mount Hope Bay from pollution, the most serious sources of pollution as indicated by Mr. Shea are the sewage and the industrial wastes from the city of Fall River. This municipality engaged Samuel M. Ellsworth, Sanitary Engineer, of Boston, in 1935 to make a sewerage survey, and Mr. Ellsworth has proposed a plan providing for an intercepting sewer by means of which the sewage from some thirteen existing outlets would be removed in a southerly direction to a point near the Tiverton, Rhode Island, boundary line where the sewage would be treated by works consisting of grit chambers, grease skimming tanks and sedimentation basins with separate sludge digestion tanks and after this treatment discharged into 25 feet of water through multiple outlets at a point about 3,300 feet offshore. The plans also provided for the chlorination of the final effluent. The floats set off from the existing sewer outlets by Mr. Ellsworth did not show that any considerable quantity of the sewage from the existing outlets reaches the pie-shaped piece of Mount Hope Bay which had not then been closed to shellfishermen.

The cost of the construction of the sewerage works in Fall River was estimated by Mr. Ellsworth in 1935 to be $2,500,000, and it is needless to say that the city, which is in a very difficult financial condition, has been unable to finance this work. In this connection it might be pointed out that the total expenditure for sewage disposal systems in Rhode Island since 1920, according to Mr. Shea's paper, has amounted to only $1,000,000 more than the estimate for Fall River. Several conferences have been held with the city government and attempts are now being made to obtain Federal funds in the construction of the necessary treatment works. Not only will the treatment of Fall River sewage improve the shellfish areas but it will remove the numerous local nuisances along the Fall River waterfront to which past generations have apparently become accustomed, but which do not meet with the approbation of the rising generation.

Mr. Shea states that the closed shellfish areas in Rhode Island amount only to 17.8 square miles, including Mount Hope Bay, or 13 per cent of the total shellfish area in the State. In this connection it might be pointed out that one area alone in Massachusetts which has been closed to shellfishing amounts to 43 square miles. It should further be pointed out, as indicated by Mr. Shea and also by Dr. Paul S. Galstoff in charge of Oyster Investigations of the U. S. Bureau of Fisheries, that the decrease in shellfish production in Rhode Island

is not due wholly to pollution and the closing of areas. It has been shown that of the extent of the areas leased for shellfish grants in 1912 there has been a decrease as of 1936 of some 73 per cent, including the areas closed because of pollution. This would indicate that the effect on shellfish may be due in part at least to starfish or other natural enemies, rather than to pollution. Nevertheless it is not to be expected that any health authority or this association should condone undue pollution of tidal waters, and in an effort to control such sources of pollution the Massachusetts Legislature in 1929 passed an act giving the Department of Public Health mandatory authority to prevent new sources of pollution in areas from which shellfish are taken within the limits of Barnstable, Dukes and Nantucket counties. Furthermore there is now a bill before the present Legislature which would extend this authority to cover the entire coast line of Massachusetts, and in addition there is another bill before the present Legislature which would authorize the Department of Public Health from time to time after notice to all persons interested and a hearing to prescribe and establish regulations for the purpose of preventing pollution or contamination of any or all lakes, ponds, streams, tidal waters and flats or the tributaries of such tidal waters and flats.

In addition to this proposed local legislation there are at least two bills before Congress having to do with stream pollution, namely, the Vinson-Barkley Bill and the Lonergan Bill, and there is some indication that the Vinson-Barkley Bill may be adopted. This provides for an annual appropriation of some $700,000 which can be allocated to states for stream pollution investigations, while the Lonergan Bill provides drastic laws for the prevention of pollution. Hence it appears likely that this year, or shortly, local and Federal legislation may be adopted by means of which stream pollution may be corrected.

Industrial Wastes

INDUSTRIAL WASTES AND THEIR EFFECTS ON MUNICIPAL SEWAGE TREATMENT PLANTS*

By L. F. Oeming

Sanitary Engineer, Michigan Stream Control Commission, Lansing, Mich.

The problem of industrial waste disposal has been the subject of increased interest during the past three years in Michigan, along with the active progress made in the construction and operation of municipal sewage treatment plants. Increasing industrial activity, as the state emerged from the depression, has been accompanied by new problems both for the designer of proposed sewage treatment plants and for the municipal official charged with the operation of existing plants. In the case of new plants, problems have arisen in the treatment of wastes from established industries in combination with the municipal sewage. New industries, contributing additional loads not provided for by existing sewerage facilities, constitute another phase of the problem. Where new plants are placed in operation, it is assumed that the designing engineer was acquainted with the nature of the problem and has provided a plant which will take care of the combined waste. The operator's responsibility in such a plant is to inform himself as to its proper operation. If the plant is already in existence, you as operators will be called upon to give an opinion as to the advisability of assuming the burden of additional loads from trade wastes.

While the methods of treating domestic sewage are more or less standardized, comparatively little is known about the treatment of combined trade and domestic wastes. Due to the differences in character, strength and volume of wastes from various types of industry and their proportion of the total sewage flow, the problem is extremely variable. It is the purpose of this paper to discuss some of the effects and difficulties which may be encountered when certain industrial wastes are discharged into municipal sewerage systems and treatment plants.

The major considerations involved in the introduction of trade wastes into a sewer system for joint treatment with municipal sewage are:

1. Will the wastes damage the sewer system?
2. Is the waste amenable to existing processes of treatment?
3. Can the sewage treatment plant handle the additional volume of industrial waste?

* Presented before the Twelfth Annual Meeting of the Michigan Sewage Works Association, Lansing, Mich., April 22, 1937.

4. Is the strength of the waste sufficient to interfere with the treatment process?
5. What will be the effect on the final plant effluent?

The industrial wastes selected for discussion are typical of Michigan. They are from milk products factories; oil refineries, garages and other sources having waste oils; canning factories; pulp and paper mills; meat packing plants; metal treating and plating plants; tanneries; and beet sugar factories.

The introduction of each of these wastes into a municipal sewerage system presents a different problem, varying with the type of industry as well as with industries of the same classification. In studying the effluents from these sources it is desirable to convert the oxygen demand of the waste into population equivalents, in order to compare the proposed additional load with the capacity of the treatment plant. The value usually used in this conversion is 0.167 pounds of five day B.O.D. per capita per day.

Milk Products Factory Wastes

The waste from this industry arises mainly from the washing of milk cans, floors and utensils in receiving stations, bottling plants, condensaries, creameries and cheese factories. Buttermilk and whey from the latter two types of factories should be considered as by-products and should not be discharged into the sewer system for the reason that they are too concentrated to be handled economically at a sewage treatment plant.

Milk waste is highly organic in nature and carries an average five-day B.O.D. of 1,000 p.p.m., which is from 5 to 7 times that of normal domestic sewage. The average milk plant whose daily milk intake is in the neighborhood of 100,000 pounds will produce 20,000 to 30,000 gallons of waste per day. On a B.O.D. basis this waste is equivalent to the sewage from 1,500 people.

The organic matter is mostly in solution or colloidal suspension. Reductions in B.O.D. cannot be obtained by sedimentation alone. Consequently, treatment plants employing primary sedimentation only should not attempt to treat milk wastes since the net result may be a substantial increase in the B.O.D. of the final effluent.

Sedimentation tank effluents of the mixed wastes will respond to oxidation on trickling filters if the waste is applied in a fresh condition. Sedimentation periods over one hour are not recommended for mixed wastes for the reason that lactic and other organic acids are produced, and they inhibit bacteriological growths on the filter media.

Although trickling filters are adaptable to the treatment of domestic sewages containing milk wastes there are many limitations to their application. A few general rules to be followed in this respect are: first, if a final B.O.D. of 80 p.p.m. or greater is acceptable, a mixed waste having an initial B.O.D. up to 400 p.p.m. can be applied up to a rate of 1 m.g.a.d.; second, if a B.O.D. below 80 is desired the propor-

tion of milk waste to sewage should be such that the initial B.O.D. will not be greater than 200 at the same rate. Third, where the filter area available is such that rates above 1 m.g.a.d. are necessary, milk wastes should not be added to sewage without pre-treatment. Fourth, if the volume of milk waste is greater than 25 per cent of the volume of the sewage or if the B.O.D. of the mixed waste is in excess of 400, pre-treatment of the milk waste should be required to reduce the combined B.O.D. to or below this figure.

Much the same rules apply to the combined waste when subjected to treatment by the activated sludge process, that is, if satisfactory final B.O.D.'s are to be maintained, the initial B.O.D. should be not greater than 400.

The other consideration of importance in accepting milk wastes for treatment is the unavoidable increase in odors. In many cases this may necessitate pre-chlorination for odor control.

Some notable examples where difficulties have been encountered with milk wastes are at Adrian, Sparta, Mason, Bad Axe, Harbor Beach and Zeeland. In these cases the milk wastes have contributed to increased costs of construction and operation and in some instances have made necessary the installation of additional treatment units.

Oil Wastes

Oil wastes originating from oil refineries, garages, service stations and automobile plants, do not add appreciably to the initial B.O.D. of the sewage, but have detrimental effects on sedimentation and oxidation by trickling filters or the activated sludge process, thereby decreasing plant efficiencies. In addition to these effects, oils present a serious fire hazard.

In no case should oil be allowed to enter the sewage treatment plant. Where oil is present, its source should be located and its discharge eliminated. Disposal at the plant may be accomplished by skimming and burning. The most recent and troublesome oil problems have been experienced at Alma, where a number of refineries are located.

Canning Factories

Wastes from canning operations consist of the washings of the product and canning equipment. The volume and strength of these wastes vary with the type of factory and the products manufactured. The so-called full-line cannery, in which a number of different packs of both vegetables and fruits are made in season, contributes large volumes of wastes which are comparatively low in strength. Specialized factories, such as those processing tomatoes, peas and other vegetables, produce wastes which are comparatively low in volume and high in B.O.D. Wastes from canneries processing fruit are usually high in volume and low in B.O.D.

Typical B.O.D.'s of canning factory effluents are:

	Parts per Million
Peas	1,400
Green Beans	159
Corn	625
Tomatoes	848
Lima Beans	189
Squash	10,800
Red Beets	7,000

These wastes contain considerable solids in suspension and will therefore influence the operation of sedimentation and digestion units. Much of the suspended matter is colloidal and does not settle readily. Large volumes of sludge are produced, overloading available sludge digestion units and promoting foaming. Acid sludge digestion predominates with accompanying high CO_2 content in the gas and low heat values.

The settled effluent responds to biological treatment processes but some difficulty may be experienced with clogging of trickling filters caused by the light suspended matter. The decomposition of this material on the filters produces disagreeable odors and may necessitate odor control measures.

Plants of the chemical precipitation type are generally more suitable for the treatment of cannery wastes in combination with domestic sewage than those employing biological processes. However, in plants of the chemical type, studies should be made to determine anticipated additional sludge volumes in order that existing sludge disposal facilities will not be overloaded.

Frequently existing sewage treatment plants are able to handle cannery wastes if they have been subjected to some pre-treatment at the factory. In any event, when pre-treatment is not used, the wastes should be passed through fine screens, prior to treatment at municipal plants.

Pulp and Paper Mills

The major wastes from mills manufacturing pulp from wood stock are the result of treatment of the stock by either of two processes, namely the sulphite and sulphate processes. In the sulphite process, calcium bisulphite is used and processing results in a waste known as the sulphite liquor. Treatment of this liquor should never be attempted at a municipal sewage plant since the chemical constituents it contains will upset any treatment process. Those mills using the sulphate process usually recover the active ingredients and rarely present treatment problems.

Waste from mills in which paper is manufactured from wood, rags and waste papers is largely the so-called whitewater from the paper machines. This waste is large in volume and usually contains a considerable amount of fiber, filter alum and dirt. Of these constituents the major portion is fiber which is of value to the industry. The problem is, therefore, mainly one of reclamation of the valuable fiber.

Municipal sewage plants attempting to treat the average whitewater

would be seriously overloaded both from the standpoint of sedimentation volume and sludge capacity. This is illustrated by the results of a whitewater survey made by the Stream Control Commission at a small Michigan mill last summer. This mill discharged 1,300,000 gallons of waste from a production of 17 tons of paper daily. An analysis of this waste showed 7,900 pounds of suspended solids daily of which 6,417 pounds were paper fibers. This represented 19 per cent pulp loss based on paper produced. The B.O.D. of this waste was 60 p.p.m., representing a population equivalent of 3,832, or 225 per ton of product.

The solution of this and other paper mill problems lies in the re-use of the whitewater and recovery of the fiber. The economical limits of recovery and re-use have been established at one per cent fiber loss and waste volume of 20,000 gallons per ton of product. Where mills operate within these waste limits it is generally found that the waste may be discharged to streams without treatment.

An outstanding example of the effects of whitewater on a sewage treatment plant has occurred at Monroe where considerable difficulty has been experienced with excessive volumes of sludge. A minor difficulty which does not affect the treatment process is caused by dyes used in the paper manufacture. These dyes are in solution and are carried through the plant affecting the appearance of the final effluent.

The major waste from mills manufacturing straw board is a composite of water from the paper machines and the alkaline wastes from the beaters, where the straw is washed after digestion in the cookers. The volume of these composited wastes averages about 40,000 gallons per ton of product and the suspended solids 2,500 p.p.m. or about 800 pounds per ton of product. The oxygen demand is 900 p.p.m. and the population equivalent is 1,800 per ton of product.

Except in large cities where the volume of the waste is a very small proportion of the total sewage flow, this waste should be treated separately by the industry rather than at the municipal sewage plants.

Meat Packing Plants

The wastes from meat packing plants consist largely of killing floor washings, which contain blood, a small amount of paunch manure and grease. This waste is comparatively low in volume and high in B.O.D. As an example, at a large meat packing plant in Grand Rapids the volume of waste was about 5,000 gallons per day and the B.O.D. was 2,000 p.p.m. The equivalent population of this waste was 500. Except for the difficulties which may be experienced with grease, this waste can usually be handled in municipal sewage treatment plants, since it will respond to either biological or chemical processes. The grease problem may be solved by skimming at the factory or by installing a grease-removal device at the treatment plant. Where the waste is accepted for treatment, regulations should be imposed upon the industry for the handling of the paunch manure. This material should

not be discharged to the sewer but should be hauled away in a solid state.

Metal Plating and Treating Plants

The principal wastes from metal-treating industries are the acid wastes from the pickling vats and the cyanide wastes from plating rooms. The pickling liquors consist largely of sulphuric acid and ferrous sulphate. These wastes in any large quantity impose deleterious effects on sewer systems and may completely upset any sewage treatment plant unless they are neutralized prior to their discharge from the factory. Small quantities when neutralized by dilution with sewage, such as would be the case in large cities, might not be noticeable at the sewage plant although even in these cases certain sections of the sewer system may be affected.

Cyanide wastes may result either from washings of metals plated or dumping of a vat containing the spoiled cyanide solution. These wastes are extremely toxic and unless diluted to a considerable degree are harmful to all biological purification processes. In chemical purification plants, the waste will pass through without affecting the process.

Usually the dilution afforded by the sewage is sufficient so that the washings from the plating room will cause no trouble at the sewage treatment plant. Concentrated cyanide solutions from the vats should not be discharged into the sewer unless dilution is such as to provide a cyanide concentration below 1 p.p.m. at the sewage plant. This may be accomplished by allowing the vats to be discharged over a long period of time.

An illustration of the effects of plating room wastes on an activated sludge plant is the recent difficulty experienced at Muskegon Heights. Studies indicated that the troubles were due to the accumulation of copper from copper cyanide in the sludge digestion units. In this instance, it was the copper which caused the difficulty, the effect of the copper being cumulative since it was precipitated as the oxide, the cyanide passing through the plant in solution.

Tanneries

In the tanning industry there are two types of tanning processes, namely the vegetable tan and the chrome tan. The vegetable tan process consists of treating the hides with an extract of spruce or cedar or other bark, while the chrome tan process makes use of a solution of chromic acid. The wastes from the vegetable tan process contain more organic material and are therefore higher in oxygen demand. A typical analysis of the vegetable tan waste shows a volume of 200,000 gallons per day, average suspended solids 3,500 p.p.m. and a B.O.D. of 1,300. The population equivalent of this tannery was 14,000. A typical chrome tannery in Michigan discharged 615,000 gallons of waste per day, carrying 1,900 p.p.m suspended solids and 600 p.p.m. B.O.D. Population equivalent of this tannery was 18,000. It is obvious from these analyses that the major effect of these wastes upon

sewage treatment processes is an increase in sludge volume. The vegetable tan liquor is highly colored and while this factor would not affect the treatment process, the appearance of the plant effluent would be impaired. The presence of these wastes would greatly increase the B.O.D. load on secondary units. Generally speaking, existing plants should not attempt to treat these wastes.

Beet Sugar Factory Wastes

The four major wastes from a beet sugar factory are flume, process, lime cake and Steffens. The combined volume of these wastes from an average factory is 3,900,000 gallons, of which 72 per cent is flume water, 22 per cent process water, 3 per cent lime cake and 3 per cent Steffens. Flume water, although comparatively large in volume, is comparable in strength to domestic sewage. Its population equivalent is 21,000. The grit removal problem is one of the major problems in the treatment of this waste, since it contains 6 cu. yd. per million gallons, or about 40 times the amount of grit in domestic sewage. The ordinary grit removal facilities at existing sewage plants are inadequate for handling this quantity of material.

The volume of sludge produced per m.g. of flume water is about 7,000 gallons, containing 15 per cent solids. This sludge is extremely heavy and would greatly tax sludge handling equipment such as pumps and digestion tanks.

Process water, although less in volume than flume water, is considerably higher in B.O.D. The average B.O.D. is 1,200 and the population equivalent 40,000. Where the existing plant has sufficient capacity to accommodate the additional volume, this waste may be admitted to the system if it is first passed through a fine screen to remove the pulp. The load upon secondary treatment, however, may be greatly increased because of the high B.O.D. The advisability of admitting this waste hinges upon the strength of final effluent desired.

Lime-cake slurry contains too large an amount of solids to handle in sewage treatment plants. If this waste is first ponded to remove the bulk of the solids, the drainage may be acceptable for treatment, although the same limitations apply to this waste as apply to process water.

The waste from the Steffens process should not be admitted under any conditions to municipal sewage treatment plants. This waste is extremely alkaline in character and carries a B.O.D. of about 50,000, consequently it would greatly overload any existing treatment facilities. It has a population equivalent of approximately 200,000 for an average factory.

In conclusion, it is apparent from this discussion that the question of admitting industrial wastes to municipal sewage treatment plants is one requiring considerable study of each individual case.

This study involves the determination of ratios of industrial waste to sewage and the effect of volume, strength and character of the waste upon the process employed, upon the capacities of the various treatment units, and upon the final effluent.

Operators' Reports and Suggestions

W. D. Hatfield
219 Linden Place
Decatur, Illinois

STANDARD METHODS OF SEWAGE ANALYSIS

Committee on Methods of Sewage Analysis, Federation of Sewage Works Associations.
W. D. Hatfield, *Chairman*

"Provisional Standard Methods of Sewage Analysis" was published by the above committee as its final report in *This Journal*, Vol. VII, pp. 449–491 (May, 1935). The above Chairman was a member of the Joint Editorial Board which edited the Eighth Edition of Standard Methods for the Examination of Water and Sewage (1936) for the American Public Health Association. The following is quoted from the third paragraph of the preface of the 8th edition, page XI.

> In May 1935, the Federated Sewage Works Association published "Provisional Standard Methods of Sewage Analysis." These methods have been adopted and included as standard with only such modification and editorial changes as were necessary for coordination with chemical procedures for water analysis. Thus for the first time, the volume will include methods for the examination of sewages, effluents, industrial wastes, grossly polluted waters, sludges and muds, *backed by the authority of the association most directly concerned.*

Some few changes, corrections and improvements were made by your chairman at the suggestion of individual members of your committee and the Association. These changes are as follows:

Odor Determination.—The procedure is given in much greater detail in the water section than in the original report, pp. 447–8. The term "dilution ratio" was changed to "odor concentration" and the equations for calculation were simplified as follows:

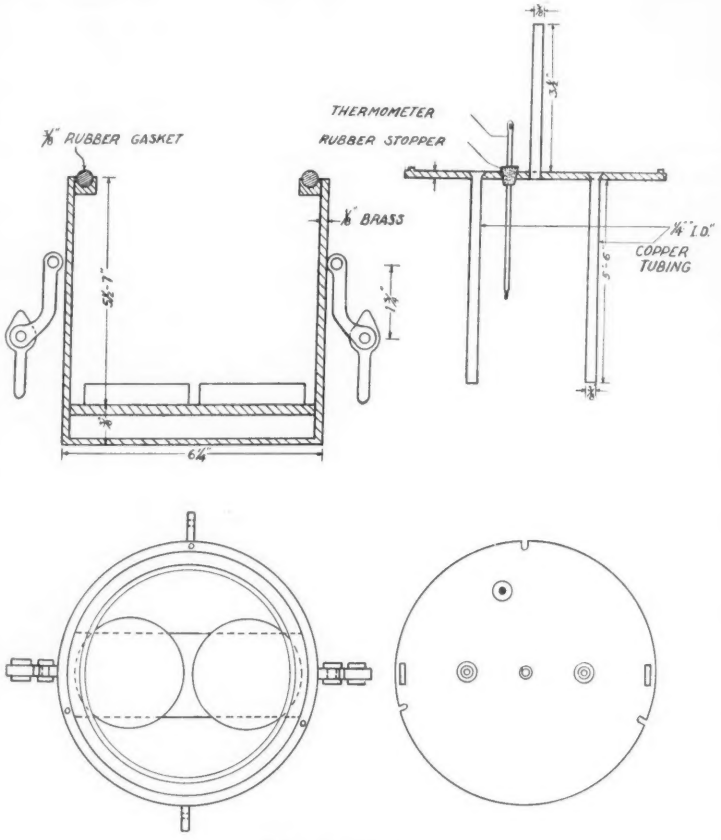
$$pO = 3.32 \times \log. \text{ "odor concentration"}$$

$$\text{Odor Concentration} = 2 \text{ to the } pO \text{ power} = \text{anti log. } (0.301 \times pO \text{ value})$$

Nitrates by the Phenoldisulfonic Acid Method.—Interfering chlorides and nitrites (p. 456) are limited to 130 and 0.25 p.p.m. instead of 120 and 1.0 p.p.m. in the portion examined.

Dissolved Oxygen Sampler.—The dissolved oxygen sampler originally described on page 459 was discarded in favor of the air-tight sampler, which is sealed by a rubber gasket between the top and body of the sampler. A simplified drawing of the new standard sampler is shown in Fig. 1. It is not necessary to use this design, but an *approved* sampler must be air and water tight except for the inlet and outlet tubes.

Starch Paste (p. 460) was changed from arrowroot to potato starch on the suggestion of the boiler-water committee. This change makes



D.O. AND B.O.D. SAMPLER

FIG. 1.

no difference in sewage work but was desired for boiler water work with very low oxygen contents.

Because of its importance in sewage work the dissolved oxygen procedure was moved entirely from the water section to the sewage section and to this was added the Oxygen Solubility Table which did not originally occur in the committee's report.

B.O.D. Calculation.—A typographical error in line 7 on page 473 was corrected as follows:

$D.O._1 = (D.O.$ in incubated blank $\times p)$ plus (D.O. in sample $\times P)$, the final p in the equation being capitalized.

The tentative *procedure for B.O.D. on chlorinated sewages* (p. 473) was transferred from Part III to the appendix where all provisional methods are assembled.

Residual Chlorine.—The titration method for residual chlorine (p. 481) in neutral solution at lowered temperatures was moved to the appendix, but is given there in much greater detail than in our provisional report.

This new eighth edition of "Standard Methods of Water and Sewage Analysis" published by the American Public Health Association should be in the hands of all chemists having any contact with the field of water, sewage or trade wastes.

There are a few corrections which should be made in the original provisional report if it is still being used.

The pO Table (p. 448), last column under dilution ratio, and column headed dilution, first two lines:

pO	dilution 1:1 (*i.e.* no dilution),	ratio	1	2^0	1
pO	dilution 1:2	ratio	2	2^1	2
pO	dilution 1:4	ratio	4	2^2	4

etc.

(p. 462) end of line 14. 2.1M should be 0.1M.

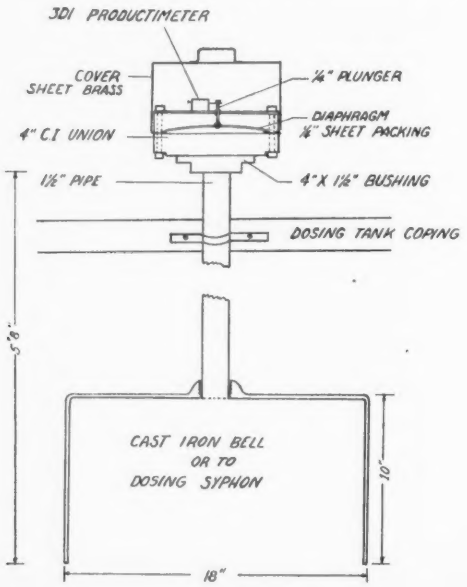
(p. 473) line 7. Small p should be capital P in (D.O. in sample $\times$ P).

(p. 475) line 13. Equation should be

$$S \quad 100\ (1 - 0.794^{t}).$$

Dosing Siphon Counter.

The dosing siphon counter is easily made up with standard pipe fittings, some ¼ in. sheet packing and a counter, at a most reasonable



DOSING COUNTER

Fig. 2.

cost. Both siphons at Decatur are equipped with counters made at the following cost.

1 3D1 Productimeter	$4.88
1 4-inch flange union	2.00
1 1½ × 4-inch bushing	.35
2 oz. ¼-inch sheet packing	.10
Misc. bolts, etc.	.40
TOTAL	$7.73

W. D. HATFIELD

TRICKLING FILTERS

BY W. H. WISELY

Excerpt from The Digester, Ill. State Dept. of Health

The "work-horse of the sewage treatment works"—the trickling filter! No other one unit can take punishment and cause as little worry as this. The way in which it has stood the test of time (trickling filters are quite venerable, compared to other modern units) establishes it as probably the foremost pioneering development in the field.

The term "trickling filter" is applied here to the so-called "sprinkling filter" as well. Both units are similar in characteristics and operation, the divergence in name coming only from the different methods of sewage distribution employed.

Purpose.—Fairly complete settling must be given the sewage before application on a trickling filter which is classified as a "secondary" treatment unit. Similar to activated sludge units, its purpose is to remove the fine suspended matter which will not settle and as much as possible of the dissolved organic matter in the sewage, which forms of sewage solids can not be removed by sedimentation. Another settling tank of smaller capacity than the primary should follow the filter.

What is a Trickling Filter?—The major parts of a trickling filter are (1) the distribution system, including the dosing tank, (2) the gravel or stone filter media, and (3) the underdrain system.

Various methods of distributing the sewage over the filter are in use but whatever type of distribution is used, it must result in a uniform application of sewage over all parts of the filter surface. The dosing tank is necessary to bring about uniform distribution where spray nozzles are used. In the case of the revolving distributor, the dosing tank is not always necessary. In Illinois, limestone is the most commonly used filter media. It is graded in size from 4 to 6 inches at the bottom to 1½ to 2½ inches in size at the surface. Depths of stone range from 6 to 8 feet. The underdrain system comprises a concrete floor which supports or encloses a system of tile channels which reaches

to all parts of the filter bottom and discharges to the filter effluent channel or conduit. A properly installed underdrain will give good ventilation to all parts of the filter.

In a few words, the trickling filter is merely a highly porous bed of stone, so built that air can reach all parts and equipped with a device affording uniform distribution of sewage over the surface.

In building a trickling filter we are simply providing a "workshop" for our friends the oxidizing bacteria. In the filter we bring the sewage to the myriads of microscopic plants and animals living in the jelly-like slime which coats the stone, whereas in the activated sludge process we brought the "workmen" (in the activated sludge) to the sewage. The settled sewage is applied to the surface of the filter in fine particles and as it trickles over the stone, the fine, unsettleable solids are absorbed by the slime in which the bacteria live. At the same time, the dissolved organic matter in the sewage is brought into contact with the bacteria or "workers" who "oxidize" or transform the objectionable matter into substances which are not objectionable. Since this process must be carried on in the presence of oxygen, you can see why the filter is built so that air can penetrate into all parts.

Much of the organic matter taken out of the sewage is stored up in the filter over a period of several months and then is abruptly dropped or "sloughed" out with the filter effluent over a period of several days. This is a perfectly normal phenomenon which frequently disturbs an operator who finds more settleable solids in the filter effluent than is contained in the raw sewage. The sloughs usually come with the changing temperatures in the Spring or Fall in a normally loaded filter.

The material sloughed from the filter or "filter humus" is fairly well stabilized and is very unlike the sludge obtained from primary settling tanks. The final settling tank (receiving the trickling filter effluent) has little to do most of the time but becomes an important unit during sloughing periods when it must keep the filter humus from reaching the outlet stream. The final settling tank sludge (humus) is usually pumped back to the raw sewage where it is again settled out in the primary tanks and pumped to the digestion units. Direct pumpage of the final settling tank sludge to digesters is not considered good practice, mainly because of the very high moisture content.

Efficiency of Trickling Filters.—Under normal loads, the trickling filter will produce a stable effluent with a good dissolved oxygen content although it may be slightly more turbid than that from a well-operating activated sludge plant. The trickling filter effluent usually has a higher nitrate content (which is generally desirable) than that from activated sludge treatment. Overall plant efficiency will range from 85 per cent to 95 per cent removal of B.O.D.

The effluent from a trickling filter plant may sometimes show a higher B.O.D. (30 to 40 p.p.m.) than is ordinarily considered good but the presence of nitrates will show that purification has progressed to an adequate extent to prevent objectionable conditions in the outlet stream. Because of an irregularity in the rate at which

oxidation proceeds in the later stages of treatment, the B.O.D. determination is not always fair to the trickling filter.

To check the load carried by your filter the B.O.D. of the applied sewage in pounds per day should be determined (flow in m.g.d. $\times$ 8 1/3 $\times$ p.p.m. B.O.D. of settled sewage). This figure divided by the area of the filter in acres will give a result expressed in "pounds 5 day B.O.D. applied per acre per day." A loading of 1,800 to 2,000 pounds 5 day B.O.D. per acre per day may be considered as normal.

Shock loads such as those imposed by some industries are absorbed very well, to a reasonable degree, by the trickling filter. The effect of a temporary overload is rapidly overcome with little appreciable interference in plant efficiency.

Editorial

THE ANNIVERSARY VOLUME

The publication of a memorial volume will celebrate the Tenth Anniversary of the founding of the Federation of Sewage Works Associations. Plans for the preparation of this volume have progressed sufficiently to permit an announcement at this time of the purpose and scope of the book.

Last September Mr. Emerson sent to each member of the Board of Control a ballot on the various possibilities available for celebration of the Tenth Anniversary of the Federation. The vote was almost unanimously in favor of a memorial volume. In January of this year it was decided officially at the Annual Meeting in New York that a book should be published, which should contain contributions invited from leaders in sewage work, the book to be sold at a low cost without intention of profit.

The next problem was to find some competent authority, eminently able to act as editor of the book, who would be willing to give time and effort gratis to the preparation of the plans and the direction of the undertaking. The Federation is fortunate to have secured Mr. Langdon Pearse for this task. He hesitated at first to give his assent, because of the amount of work involved, but finally agreed to tackle the job and has been working closely with Mr. Emerson, with suggestions from others, on the selection of topics and authors.

This book promises to be unique—of such distinction and authority that it will be prized by all workers in the field of sewage disposal and also by many laymen who may enjoy the opportunity to become acquainted with the nature and scope of this fascinating field of science and sanitation. To the esoteric circle of those now active in sewage work, this book will be treasured because it will contain contributions from some thirty or more men in this country and abroad, comprising discussion of topics closely related to the life work of these experts. This personal touch will lift the book out of the class of textbooks or handbooks and elevate it into the field of memoirs or scientific autobiography without, however, losing the value of scientific instruction in the selected subject.

Mr. Pearse makes the following statement:

> "The anniversary volume will be based on the idea of a convention without a metting place, whereby some thirty papers will be presented by well known personalities who are practicing in the field of sewage disposal.
>
> "It is planned to arrange a logical program to cover in a modest volume the field of sewage disposal, in a different manner from the conventional textbook. Specific topics are to be assigned to the various authors to bring out their fields of activity in a broader way than a review restricted to the personal experience of each contributor.
>
> "As the plan progresses, invitations will be extended not only to those in the United States, but also to some of our foreign friends. This plan will recognize the presence of foreign affiliate associations in the Federation, and will emphasize the international interest in the progress of sewage treatment.
>
> "This program should be of more general interest than the preparation of a technical manual, for it makes it possible to preserve the fruits of experience of those who for many years have been active in sewage

work. As yet the program is still in a state of flux. When the various authors have been selected, it is hoped that requests for contributions will receive their careful consideration and hearty cooperation.

"The anniversary comes in the Fall of 1938. The dead line for the printer will be about a year from now, so the various authors should have ample time to arrange their literary budget.

"We are further assured by Mr. Buffum of his hearty cooperation in managing the enterprise.

"Further announcement will be made as the plans mature."

We may therefore expect something of fine and permanent value to commemorate the first ten years of the life of the Federation. We will grieve because the book will not contain contributions from two of the most distinguished sanitary engineers in America who have died in the past few years—George W. Fuller and John H. Gregory—whose professional careers should be an inspiration to the younger generation. George W. Fuller was vitally instrumental in the organization of the Sewage Works Federation and he always took a keen interest in its advancement. The writer suggests that the anniversary book be dedicated to his memory.

F. W. M.

THE PASSING OF FRIENDS AND COLLEAGUES

Prof. John H. Gregory's death in January is still a shock to his friends and colleagues. He had been so active up to within a few days of his death that it has been hard to realize that we can no longer have his wise counsel and friendly greeting. His memory will be preserved by the library founded in Columbus, Ohio, by provision in his will. This memorial seems poignantly fitting for a man who was always keenly interested in the literature of sewage treatment as well as competent and experienced in the practical field of design and construction.

Death also came suddenly May tenth to Gus H. Radebaugh, well-known manager of the Urbana-Champaign Sanitary District. Gus was no erudite scholar nor technical expert, but he was a genius in selling sewage treatment throughout his section of the country and he was a personal friend of hundreds of men in his profession. He was the dynamic personal force behind midwest sewage works associations and was well-known nationally for his ability to make the public sewage-treatment conscious.

Word has just been received that F. R. O'Shaughnessy, well-known chemist of the Birmingham, England, plant, died May thirteenth at the age of sixty-two. Mr. O'Shaughnessy contributed much to the advancement of sewage treatment and was an international authority. His level head and conservative judgment will be missed among the councils of our English affiliates.

F. W. M.

Reviews and Abstracts

H. W. Streeter

THE BIOLOGIC DIGESTION OF GARBAGE WITH SEWAGE SLUDGE

By H. E. Babbitt, B. J. Leland and F. H. Whitley, Jr.

Bulletin No. 287, Engineering Experiment Station, University of Illinois, Nov. 20, 1936. 112 pp.; five appendices. Price, $1.00.

Increasing public interest in the possibilities of the water carriage system for collecting garbage points to an increasing load of pollution on natural watercourses receiving municipal sewage, or on plants designed to treat such sewage before disposal. The problems thus created will involve the capacity and ability of plumbing and sewerage systems to convey ground garbage suspended in water, the nature of load imposed on sewage treatment plants and natural watercourses, and the economics of the method.

The objects of these tests were to study the nature and intensity of this load, the capacity of digestion tanks to carry it and the division of the load between primary and secondary sewage treatment processes. Studies were restricted mainly to digestion of garbage with fresh sewage sludge and to methods for dosing digestion tanks.

For the large-scale tests, four circular tanks were used, located at the Sewage Testing Plant of the University, which is supplied with sewage from a 30-inch outfall main. Tanks *A* and *B*, each 28 ft. deep, were equipped and operated as Imhoff tanks. Tanks *C* and *D*, each 17 ft. deep, were used, respectively, for two-stage digestion and for plain sedimentation. Small-scale digestion tests were made in 50-gal. oil drums, in 5-gal. carboys, and in one and two gallon glass bottles. Garbage was ground in a farm-type grain grinder and, for finer comminution, reground through a domestic meat grinder. Tanks *A* and *B* were roofed in some tests for gas collection and Tank *C* was arranged so that gas could be collected and measured separately from the primary and secondary compartments. The gasometers were counterbalanced to a pressure less than ¼-inch of water. Brine solution used to seal the gasometers was never changed, but small quantities were added as needed to maintain the seal. Samples of raw sewage and effluents from tanks *A* and *B* were collected hourly by an automatic device and composited over 24-hour periods.

Garbage for the tests was collected from restaurants, residences and similar institutions in the district. It was classified as "clean" garbage in that it was free from any materials except waste food. It was fresh when delivered daily to the plant. After draining in a container having a perforated bottom, the material was hand picked to remove inorganic, inedible and lumpy materials, and then ground for the digestion tests.

Digestion of Garbage Solids Seeded with Sewage Sludge

Preliminary tests were made on mixtures of garbage and sewage sludge digested in batches, without the further addition of solids. It was concluded that seeding the garbage with sludge could be accomplished if 10 per cent or more of the volatile solids in the mixture originated in the sludge. In subsequent tests the percentage of sludge volatile solids was made more nearly 40–50 per cent, approximating conditions expected in the operation of a sewage treatment plant receiving garbage. The impracticability of digesting organic solids by batch digestion was demonstrated by these preliminary tests.

Dosing Imhoff tanks with ground garbage was tested in identical tanks *A* and *B*, dosing both tanks with the same quantity and quality of sewage and applying garbage to one of the tanks in addition to the sewage. In the first series of tests, it was clearly

shown that this method of dosing Imhoff tanks with garbage would not work well. Quantities of solid matter floated across the tank to be discharged with the effluent. Interposition of scum boards did not improve the character of effluent, which continued to be choked with solid particles sucked under the surface baffle. When ground garbage was added to the sludge compartment of tank *A*, measurements of volume of accumulated sludge were meaningless because the sludge tended to rise in the sludge compartment. Finally the gas vents became clogged and unbalanced pressures of liquids and gas caused the collapse of the sides of the flowing-through compartment. It was concluded from these results that it is not practicable to attempt to digest garbage in any digestion tank without mixing intimately the material with the liquid in the digestion compartment.

In the third series of tests, the ground garbage was mixed thoroughly with the sewage entering tank *A*, or to tank *B*, but never to both tanks at the same time. During the period of the test, 17,352 lbs. of garbage were put into tank *A* and 1,290 lbs. into tank *B*. Each tank received 11,000,000 gals. of sewage. Tank *A* accumulated 34.5 cu. yds. of thick sludge and tank *B*, 6.4 cu. yds. It would not be correct to assume that the difference between these quantities represents the amount of garbage added to tank *A*, because even with both tanks receiving sewage alone, the accumulation of sludge was more rapid in tank *A*. This series of tests indicated that the addition of ground garbage to the influent of an Imhoff tank did not interfere with the digestion in the tank, provided the rate did not exceed 1.5 tons of garbage per million gallons of sewage. The volume of sludge accumulated after a digestion period of one year was about 2 cu. yds. per mil. gals. of sewage per ton of garbage added to the sewage. It was probable that much more sludge was accumulated during the normal digestion periods allowed in full size sewage treatment plants. Successful operation at higher rates of garbage addition was indicated, but no tests were made at higher rates in this investigation.

Tests were made of the digestion of ground garbage with fresh sewage sludge in a two-story digestion tank, with a view to determining the capacity of such a tank, with temperature control. The rate of charging the digestion tank with combined sludge and garbage varied between 0.34 and 1.67 lb. of volatile solids daily per cu. yd. of digestion capacity. This is equivalent to 0.38 to 1.85 lb. of volatile solids monthly per cu. yd. of digestion capacity. On the basis that 200 p.p.m. of solids are removed from sewage by plain sedimentation, the ratio of wet garbage to sewage varied between one and three tons per million gallons of sewage treated. Reduction in the period of digestion from 60 to 30 days apparently had no unfavorable effect on the operation of the tank, as there was no change in volatile acids or pH, and the volatile solids remained constant, though the rate of charging with volatile solids was almost doubled. All indications are, therefore, that the tank can digest successfully more than 1.67 lb. of volatile solids per day per cu. yd. of digestion capacity with a period of retention of 30 days, or possibly less.

The rate of gas production per unit volume of the primary compartment was about 150 per cent of the secondary compartment rate during the first two periods. During the third and fourth periods, the primary compartment rate was 56 and 66 per cent of the secondary compartment rate. These figures indicate a higher rate of gasification from grease floating in the primary compartment than from the heavier material that dropped into the secondary compartment. The higher secondary rate during the third and fourth periods indicated that the primary compartment was not sufficiently large to accommodate material high in grease content.

Tests also were made on the effect on digestion of garbage of its elutriation with sewage. The main purposes of these tests were (1) to measure the load on the secondary treatment devices resulting from intimate mixture of garbage and sewage before passing into the primary sedimentation tanks; (2) to observe the characteristics of garbages which have been and have not been elutriated before addition to a separate digestion tank, and (3) to determine the requisite capacity of digestion tanks to receive elutriated or non-elutriated garbage. In these tests elutriation was accomplished by placing the required quantity of ground garbage in a mixing bucket together with 15 liters of sewage and violently agitating the mixture, with power-driven paddles, for about one hour. The contents of the bucket were then allowed to stand quiescent for an hour, poured on a 16-mesh screen and allowed to drain.

From these tests the following results may be summarized:

1. The load upon the secondary treatment devices resulting from intimate mixing of garbage and sewage before passing into the primary sedimentation tanks, when expressed in terms of 5-day, 20° C. B.O.D., ranged from 27 to 115 p.p.m., averaging about 55 p.p.m. This is about half the normal load placed upon secondary devices by sewage alone passing through primary sedimentation tanks. If it is assumed that the ratio of wet garbage to sewage is 2.5 tons per million gallons of sewage, then the dumping of the garbage into the sewage will increase the total and volatile solids in the primary settling tank by 110 p.p.m.

2. Assuming the B.O.D. at half the volatile solids, both in p.p.m., the elutriation of all garbage in the sewage would be estimated to increase the 5-day, 20° B.O.D. of the primary settling tank effluent about 55 p.p.m., or a first-stage total demand of 80 p.p.m. With a 35 per cent removal of B.O.D. by primary sedimentation, it is estimated that the increased load on secondary treatment devices resulting from addition of garbage to the sewage would average about 43 per cent and range from 100 down to 25 per cent.

3. Elutriation of the garbage did not affect conditions of digestion, or reduce the pH of the sewage, but resulted in a higher B.O.D. of the sludge formed from the mixture, and in a lower percentage of grease to be digested.

4. About 66 per cent of the volatile solids and 59 per cent of the total solids in the garbage went into solution or colloidal suspension when the garbage was elutriated.

5. The elutriation of garbage will require 20 per cent more capacity in a separate digestion tank than if the garbage fed to the tank were not elutriated. More digestion capacity is required per pound of solids fed to a digestion tank by feeding with a thin sludge than by feeding with a concentrated sludge, the retention period being the same under both conditions.

The effects of adding three different alkaline chemicals to sewage treated with garbage were studied, in order to ascertain the extent to which acid conditions, unsatisfactory digestion, or foul odors could be remedied by this measure. The results of these tests indicated that lime is beneficial in overcoming acid digestion. Caustic soda or soda ash will have no beneficial effect when applied in amounts less than 2,000 p.p.m., where the volatile solids in the digesting mixture are less than about 3,000 p.p.m. Unsatisfactory acid conditions of digestion may be corrected by adding an amount of lime computed as the equivalent of the volatile acids present where the volatile acids do not exceed 4,000 p.p.m.

Miscellaneous studies included: (*a*) digestion of lumps of ground garbage, which did not affect the rate of digestion but lowered the pH after prolonged digestion; (*b*) digestion of large objects suspended in the digestion tanks; (*c*) anaerobic digestion of some pure food materials, such as cane sugar, filter paper, cotton seed oil, casein and blood fibrin, and (*d*) loss of gas through gasometer seals, which was found to be relatively appreciable only when the gas production was low.

A series of observations on the biology of anaerobic stabilization of garbage and sewage sludge was undertaken in the hope of finding an easily detectable biologic index of the progress of anaerobic digestion. Although the results of this study were negative in so far as the purpose of the investigation was concerned, they served to explain, in part, some of the biological activities in the anaerobic stabilization of organic matter. They also brought out the conclusion that foul odors in sludge digestion are the product of obligate anaerobic bacteria, and that well-digested sludges showed lower bacterial counts than did fresh sludges.

Discussion and Summary of Conclusions

The anaerobic digestion of garbage under thermophilic conditions is said to be successful in stabilizing organic matter in a few days. Some of the findings of this investigation have pointed to equal possibilities for the stabilization of sewage and garbage organic matters and point to the possibility of greatly decreasing the customary allowances for digestion tank capacities under current practice. One of the most promising indications of such a desirable finding was given by the test on the control of digestion by chemicals. The concentration of volatile solids may be a valuable indicator of opti-

mum digestion conditions. When their concentration was 80,000–90,000 p.p.m., 0.23 lb. of volatile solids per day per cu. yd. of tank capacity was produced. At this rate, it is estimated that it would be necessary to provide 1.1 cu. ft. of tank capacity per capita producing combined sewage and garbage. If a very short retention period is possible and an optimum concentration of volatile solids is 9 per cent, there would be required, for 0.25 lb. of combined sewage and garbage solids per capita daily, a digestion capacity of 0.1 to 0.2 cu. ft. per capita, depending on the retention period. If this figure were doubled to take care of daily variations from the average, the required digestion capacity would be 0.2 to 0.4 cu. ft. per capita. This indicates the possibility of designing controlled, separate digestion tanks with capacities of 10 per cent, or perhaps only 5 per cent of present requirements in the digestion compartment of an Imhoff tank, caring for sewage sludge alone. Further investigations are required to confirm the possibilities indicated.

The possibility of operating a tank with a very short digestion period is suggested from the results of the observations made during the lime-controlled tests. Because of the effectiveness of lime in controlling digestion, it may be possible, after good digestion has been established, to feed a temperature-controlled, separate digestion tank with any ratio of garbage to sewage volatile solids to the limit of 100 per cent of either of them. The volume of well-digested sludge produced may be expected to be somewhat less than twice the volume resulting from the digestion of sewage sludge alone.

The main conclusions derived from the investigation may be summarized as follows:

1. The digestion of a mixture of garbage and sewage sludge without frequent feeding and stirring of the mixture and without periodic withdrawal of the products of digestion is impracticable. The acid phase of digestion developed and could not be corrected easily. Batch operation, as this may be called, was found impracticable except for special studies.

2. Feeding ground garbage in lumps into the influent end of an Imhoff tank, or into the digestion compartment of such a tank, was found impracticable.

3. Feeding ground garbage, well mixed with sewage, into the influent of an Imhoff tank was successful when the rate of feeding did not exceed 1.5 tons of wet garbage per million gallons of sewage. Sludge accumulated at the rate of 2 cu. yds. per million gallons of sewage per ton of garbage when retained for one year in the digestion compartment. Higher rates of accumulation would result from a shorter period of sludge retention.

4. Ground garbage well mixed with sewage, was fed to a heat-controlled two-stage separate digestion tank, with constant and rapid recirculation of the digesting mixture and the temperature maintained close to 90° F. With a rate of feeding equivalent to 1.67 lb. of volatile solids per day per cu. yd. of digestion capacity with a retention period of 30 days, the required digestion capacity would be 3.75 cu. ft. per capita on the basis of producing 0.115 lb. of volatile solids from the garbage and an equivalent amount from the sewage, per capita per day. Indications are that a much shorter period of retention may be possible, with digestion capacities as low as one-tenth those used in the tests.

5. The concentration of volatile solids in the digestion tank was a good index of the behavior of the tank and its approach to the limit of its capacity. The permissible limit of this capacity was not reached at concentrations as high as 8,000 p.p.m. Concentrations as high as 80,000 p.p.m. were reached in smaller digesters and were accompanied by an increase in the rate of digestion of volatile solids.

6. Two-stage digestion compartments revealed a higher rate of gas production in the primary compartment, presumably because of the greater accumulation of grease in this compartment.

7. It was found that the water-carriage method of collecting garbage added 25 to 100 per cent to the B.O.D. load on secondary treatment devices in the sewage treatment plant, and required 20 per cent more capacity in a heat-controlled separate digestion tank than if the same amount of garbage has been fed directly into the digestion tank, together with the sludge from the same amount of sewage.

8. When garbage was washed (elutriated) with sewage, 23 to 63 per cent of the garbage volatile solids, averaging 34 per cent, went into solution or suspension.

9. Elutriated garbage digested as well as garbage which had not been elutriated.

10. Garbage grease was somewhat more easily digested than sewage grease.

11. Computations based on assumptions used in practice and on observations made during the tests indicated that temperature-controlled digesters may be operated successfully at a loading equivalent to 3.45 cu. ft. of digester capacity per capita when being fed with elutriated garbage with fresh sludge and 2.88 cu. ft. per capita when being fed with non-elutriated garbage with fresh sludge. These figures are based on a retention period of 30 days.

12. The control of digestion conditions with lime, in a temperature-controlled digester, with sludge recirculation, resulted in a peak production of 3.0 cu. ft. of gas per day per cu. ft. of tank capacity, which rate continued for only a few days. This rate is equivalent to the digestion of 0.23 lb. of volatile solids per day per cu. ft. of tank capacity. The normal rate of operation was 0.06 lb. per day per cu. ft. of tank capacity.

13. Caustic soda and soda ash were found to be of no value on overcoming acid digestion.

14. Unground garbage was not digested successfully. Indications were that the fineness of grinding is a factor in the rapidity of digestion.

15. Sludge is probably more effective than supernatant liquid as a seeding material because of the higher bacterial content of sludge. Well digested sludge showed lower bacterial counts than did fresh sludge.

The report contains five appendices, dealing with laboratory methods and other special procedures, and also a bibliography of 79 references on the subject. It is well illustrated and contains many interesting tables and charts.

H. W. STREETER

CHEMICAL METHODS OF TREATING SEWAGE. BRITISH, AMERICAN AND GERMAN PRACTICE: A SYMPOSIUM AND DISCUSSION

The Surveyor, 91 (Feb. 26, 1937), 343–347

British Practice. J. H. Garner.—Following a report by the General Board of Health in 1854, which expressed the opinion that no adequate trials had been given chemical treatment of sewage in England, there was remarkable interest in chemical treatment which developed into rivalry with disposal by irrigation on land. With the rise of biological methods in the eighties, chemical treatment fell into disfavor. About ten per cent of 3000 treatment plants use chemicals in some form, generally lime, aluminum or iron salts and sulfuric acid, with aluminoferric the most widely used precipitant. Acid precipitation is used only in four towns. Recent work has indicated substantial benefits to biological processes in the pretreatment of strong sewage by combined acid and aluminoferric dosage, mixed not to exceed 10 minutes by diffused air with a subsequent short sedimentation period. The general trend has been, however, toward complete biological treatment as exemplified by the new Mogden works.

American Practice. H. H. Hendon.—With the construction of two modern chemical treatment plants, at Dearborn and Shades Valley, there has been a revival of interest in chemical treatment processes. The reasons for this are: (1) the need for a degree of treatment intermediate between plain sendimentation and complete biological treatment; (2) the need for a simple process where the degree of treatment can be varied to meet the requirements of the incoming load, or of varying conditions of dilution in the receiving stream; (3) the need for a method of reducing the load on existing overloaded biological plants; and (4) the need for treating certain industrial wastes.

Some of the more complicated schemes adopted following laboratory or small scale tests have later been simplified, such as the discontinuation of the use of paper pulp at Dearborn and simplification of stage precipitation at Palo Alto. About fifty plants

are at present in operation, with twenty-five more under construction. The extensive development of chemical methods has been due to cheaper chemicals, better mechanical equipment and process control, and recognition of the over-all economy of the process in certain places, as well as their limitations in others.

German Practice. K. Imhoff.—No new chemical treatment plants have been built since 1905, and only two such plants are now in operation. Trade wastes are chemically treated in a good many instances. The future of chemical treatment in Germany seems limited to those places where biological methods are inapplicable, owing to trade wastes, and in places where treatment is only necessary for a few weeks or months of the year.

Discussion.—Dr. H. T. Calvert (Ministry of Health) referred to the lignite process, used at Potsdam, Germany, which he had seen in operation, and said he would not be surprised if a revival of some treatment of this nature took place in England. Germany was once again directing its energies to land utilization of sewage, and English practice might again swing towards chemical treatment.

Mr. H. C. Whitehead (Birmingham Tame & Rea Drainage Board) commented on the remarkable unanimity in the conclusions of the three authors, which were substantially the same as those arrived at by the Royal Commission in 1908. He cautioned that much of the soluble fermentable matter in sewage was left untouched by chemical methods and, where complete purification was essential, chemical treatment was not an acceptable alternative to biological methods. Chemical treatment with lime and chlorine was being successfully used at Birmingham to control septicity in gashouse liquors which were stored to provide a balanced dosage of these liquors into the sewage entering the treatment plant. The rate of sludge digestion at one plant receiving waste gas was found to be only one-quarter that of a comparable plant receiving no wastes.

Mr. J. H. Edmondson (Sheffield) considered that chemical treatment fell into three categories: (1) the prevention of septicity; (2) precipitation of solid materials; and (3) the conditioning of sludge. Mr. Hendon, regarding the second category had "certainly reduced the extravagant claims which had been made for American plants." He (Mr. Edmondson) had done some experimental work with flocculators and chemical treatment, and thought there was a field for revived investigation into their use. However, due to lower per capita use of water in England and therefore stronger sewages, the best precipitated effluent he could get at one small plant had a higher B.O.D. than the raw sewage at Shades Valley. He considered population a better basis for reporting plant results than the gallons treated.

Mr. W. K. Porteous (Westminster) considered conditioning of sludge the most practical aspect of chemical treatment in England. "There were possibilities of treating the sludge with salt instead of by chemicals and then it was possible to get down, by vacuum, to about 60 or 65 per cent of water, or by filter beds to about 35 or 40 per cent of water."

Dr. A. Parker considered chemical treatment insufficient for the needs of most English plants, since the sewages are strong and the effluents must be discharged into small streams.

Mr. P. G. Lloyd (Kingston upon Thames) stated that they had used the A.B.C. precipitation process at Kingston with good success and were able to filter the effluent at a rate of 150 gallons per cu. yd., thus holding down capital expenditures. The sludge produced was made into fertilizer, which sold for more than enough to repay the cost of charcoal used in the process. He considered a more widespread use of chemicals to assist the biological processes would be economical.

Mr. H. H. Hendon stated in regard to the strength of sewages that it frequently required more chemicals to treat a weak sewage than a strong one.

Mr. Garner stated that the opportunities for adopting new processes in England were frequently limited by the necessity of repaying Ministry of Health loans, which generally ran for thirty years, before installng new plants.

R. W. Kehr

PARTIAL TREATMENT OF SEWAGE BY THE ACTIVATED SLUDGE PROCESS

F. E. Pipe and J. E. Farmer

The Surveyor, 91 (March 19, 1937), 437–440

This paper describes the comparative working of three activated sludge plants, one using diffused air, another "Simplex" equipment, and the third paddle wheels in channels, all giving preliminary treatment to the same sewage prior to trickling filters. The diffused air and Simplex aeration units were installed in three existing sedimentation tanks 125′ long, 12′ deep, and 22, 22, and 52 feet wide, as a means of increasing plant capacity. From 1926 to 1932, when a Dorr primary sedimentation tank was installed, they were treating screened unsettled sewage.

The "Simplex" plant consists of 3 units, each comprising two aeration tanks and four sedimentation tanks which can be operated as separate plants in parallel or in series giving stage treatment. The "channel" plant contains 12 channels 4′ 6″ wide by 5′ deep, with a total run of nearly 2,500 feet, and four inverted pyramid type final settling tanks. The diffused air plant has 6 channels 12′ 6″ deep, the two outer channels being 11′ wide with two rows of diffusers and the remaining 4 being 5′ 6″ wide with one row of diffusers. Any volume from 25 to 75% of the total capacity can be used for aeration and the remainder for reactivation of the sludge.

Used as pretreatment plants with a dry weather flow of 5.5 m.g.d., the rate of treatment is 6–12 times that normally used with nearly 2/3 of the reduction usually obtained. In such partial treatment the degree to which the sludge becomes active is less and the effect seems to be the coagulation of solids and colloidal matter by a growth of filamentous bacteria. Under conditions of excessive loading or in the presence of hydrogen sulfide in the sewage, the quality of the floc deteriorates rapidly. Stagnation of solid matter in either the aeration or settling tanks results in septicity which is especially detrimental in partial treatment. The average amount of organic matter in the dry, reaerated floc is 86%. Sewage probably does not dissolve oxygen at the same rate as unaerated tap water, which would account for the better results obtained when the water is diluted either purposely or by storm flows.

"For research information, the results obtained from large scale plants working under everyday conditions bring into prominence many varying factors. The following all appear to play some part in giving the varying results:

"Amount and quality of suspended matter in the liquor under treatment; amount and quality of impurity in solution; fluctuation in flow; quantity of solids as activated sludge held in the plant; age of the activated sludge; proportion of fresh solids added to that in an activated state; time under aeration; the rate of solution of oxygen; and temperature." In a large plant it is impossible to estimate the effect of any one or more of these factors. For partial treatment, there appears to be no advantage in reaeration when, if used for aeration, the same volume treated is given a longer aeration period for the same power. The floc formed in partial treatment is different in appearance and quality from that obtained from full treatment.

The amount of sludge carried should not exceed 4 per cent for the "Simplex" and "channel" type or 5 per cent for the diffused air system as measured by 1 hour settling. Above this the floc deteriorates and may become septic. From the results obtained with pretreatment, it would seem possible to carry out sewage treatment by activated sludge in stages, each succeeding stage carrying a more highly activated sludge than the preceding one, a sludge containing organisms better adapted to their particular environment and food supply, a sequence similar to that occurring naturally in the self-purification of a polluted river.

Discussion.—Lt. Col. Temple (President of the Institute) opened the discussion by questioning whether the sludge used was activated at all and defended reactivation of the sludge since, in his experience, speeding up the return of reactivated sludge eliminated bulking. He also emphasized the necessity of avoiding stagnant pockets of flocculated material.

Mr. J. S. Alford (Westminster) expressed a conviction that preliminary sedimentation should be included in any scheme of sewage treatment since the settleable solids and liquid portions could not be economically treated together.

Mr. W. H. Hillier (London) questioned the high rates of purification obtained by the authors and stated that he thought the moisture content of the sludge (99.7 per cent) was too high. He suggested insufficient aeration and too large final settling tanks as a cause of the difficulties experienced.

Mr. R. Hicks (Gravesend) stressed the physical and chemical aspects of purification by activated sludge and stated that they were using sulfate of iron as a catalyst to promote oxygenation of the sludge with a high rate of sludge return, *i.e.*, 2/3 sludge to 1/3 sewage.

Mr. A. J. Martin (Westminster) commented on the absence of a definite comparison between the three systems.

In replying to the questions, Messrs. Pipe and Farmer stated that the partial treatment works handled the entire flow, giving two hours' detention, after which the effluent was applied to the filters at twice normal rates. The sludge had to be drawn off quickly to prevent septicity and, for this reason, sludge of 99.9 per cent water content was preferable to that with 99.7 per cent moisture since the latter was too quick. Direct comparison between the three types of plants could not have been made since it had been necessary to use each of them at its full capacity.

R. W. Kehr

DISPERSED AND COLLOIDAL MATTER IN SEWAGE

By E. V. Mills

The Surveyor, **90** (November 20, 1936), 619–22

Suspensions, Colloidal Dispersions, Solutions.—Particulate systems are classified into three main groups, those containing coarse, homogeneous particles; those containing aggregates of primary colloidal particles, and those containing only free moving primary colloidal particles. A primary colloidal particle is much larger than molecular dimensions but is smaller than the wavelength of visible light. Particulate systems consist of two phases. One phase is continuous, may contain dissolved materials and is called the dispersion medium. The particulate or dispersed phase is called the dispersate. Dispersed particles in suspensions settle at a constant rate in accordance with Stoke's law. Very small particles remain permanently in suspension on account of their tendency to diffuse.

Early studies demonstrated the presence of indiffusible matter in sewage, gave an estimate of its concentration and showed that about 80 per cent of it was of fecal origin. The dispersed particles carry a negative charge with respect to the dispersion medium. The sign of the charge on the particles is not changed by the removal of the solutes. It was concluded from the early work of Jones and Travis that the presentation of extended surfaces to sewage resulted in the transformation of organic material from practically soluble to the particulate condition. Studies with the precipitation of sewage with aluminum salts were made and showed that with these salts the precipitation was incomplete. It was shown that self-flocculation of sewage colloids occurs upon storage at ordinary temperatures and that it proceeded more rapidly at higher temperatures. Past work has also shown that sewage dispersates are chemically heterogeneous, and that, although normally electro-negative, they are amphoteric in nature.

Results Obtained from 1930 to 1933.—All sewage liquors are similar in that they contain three main types of dispersed particles. The first of these includes the settleable solids and is nitrogenous. The second fraction will not settle by gravity but can be removed by large centrifugal forces and is devoid of nitrogen. The third fraction that is not removed by centrifuging is nitrogenous and is considered as being in true colloidal dispersion. The two fine fractions have all the salient properties of colloidal particles. Ignoring the settleable solids, the dispersate constitutes one phase of a system of which the other phase includes organic solutes and mixed electrolytes.

The important properties of the dispersate are its charge and its hydration. The charge on the dispersate is sensitive to small changes in pH. Both acid and alkali result in precipitation. The alkali precipitates calcium salts and acid soluble organic matter. The surfaces produced by the primary precipitation concentrate and partially precipitate the dispersed particles.

Gas bubbles (air, oxygen, hydrogen and nitrogen) passed through sewage coagulate the two fine constituents and reduce the concentration of the organic solutes. The dispersate may also be coagulated by agitation (stirring without contact with air) but this is not so effective as coagulation with gas bubbles. In twenty-four hours, however, the greater part of the dispersate is removed by stirring. Stirring resulted in very little removal of dissolved organic solutes while bubbling with oxygen caused substantial losses of dissolved organic matter. The coagulation of sewage dispersate by gas bubbles was influenced by temperature. At 0° C. the sewage liquor was stable toward gas bubbles. At 10° C. all four gases produced a negligibly small effect. At 25° C. considerable coagulation occurred in six hours. At 37° C. the rate of coagulation does not differ much from that at 25° C. At 80° C. the coagulation proceeds rapidly and after two or three hours of bubbling, practically the whole of the dispersate is removed.

The Part Played by Dispersed and Colloidal Matter in Sewage Purification—Sedimentation.—The first stage in coagulation is the union of numbers of particles to form secondary aggregates. In this coagulation the particles are brought together from all directions by their heat movement. This has been termed perikinetic coagulation and does not necessarily result in the formation of settleable aggregates. When settleable aggregates are formed or when settling particles are present coagulation of a different type sets in. During settling the particles are brought into contact with non-settling particles or aggregates and further coagulation occurs. This coagulation is the result of a movement of particles in one direction only and it has been called orthokinetic coagulation. Orthokinetic coagulation may be very important in large scale sedimentation with great settling depths. Chemical precipitation processes are governed to a great extent by orthokinetic coagulation. Gentle agitation of a coagulating dispersion by maintaining particles in suspension assists in floc formation by the union of secondary aggregates and is an integral part of chemical precipitation processes.

Bioflocculation and Activated Sludge Process.—The first stage of these processes is the condensation of sewage dispersates on the surface of the sludge. The general properties of activated sludge are consistent with the idea that the sludge fragments (floes) are aggregates of minute particles. The density and strength of the sludge depends upon the residual hydration and charge of these particles. The size of the aggregates and their settling rate is influenced by the condition of the sludge, and the composition of the sewage, with which it is treated. Complete treatment by activated sludge results in coagulation of the dispersate and oxidation of the organic solutes. The second process is biological. Aside from biological effects trade wastes would be expected to affect the charge and hydration and, therefore, the settling and clarifying properties of activated sludge.

The Percolating Filter.—While the percolating filter and the activated sludge process have many points of resemblance, the essential difference between the methods is the widely different working conditions of the upper and lower layers of the filter. In the activated sludge process raw dispersate hinders all particles of sludge equally. In the percolating filter the raw dispersates are concentrated in the first foot of the bed and are then discharged in the form of aggregates which do not appear to hinder the activity of the lower layers of the bed. Too great a load on the filter results in ponding but the extent to which ponding is due to direct choking of the bed with condensed raw dispersate is not clear.

Sludge Digestion.—Although considerable sludge is destroyed during sludge digestion the most important change brought about by the process is the irreversible dewatering of the sludge. By anaerobic digestion all kinds of sewage sludges, with the possible exception of chemically precipitated sludges are readily dewatered. This process is a simple biological destruction of active groupings on the surface of the sludge. These sludges consist of aggregated highly dispersed particles each of which is strongly hy-

drated. These colloidal systems are characterized by their high internal surface areas which are the seat of their hydration. Both the interior and exterior surfaces of the sludge must be dehydrated. While the bacterial mechanism of the dehydration is not clearly known the penetration to the interior of the sludge is slow. Penetration is governed by pore size and pore size is dependent upon the distance separating the primary particles. The latter factor is largely determined by the residual charge on the particles. Moderately high pH values which tend to increase the charge on the particles greatly favor sludge digestion. The advantage obtained by the use of a large concentration of digested sludge is not clearly understood and it is suggested that the digested sludge may prevent the raw sludge from gelatinizing. Further study of the physical chemistry of these sludges should be valuable in explaining the mechanism of sludge digestion.

Conclusion.—"No adequate statistical data are available on the amount of dispersed and colloidal matter in sewage, and on the factors affecting this amount, nor is the influence of trade wastes on the properties of sewage dispersates fully understood. The actual amount of dispersed materials to be dealt with is of less importance than a proper understanding of the practical methods required for their treatment; in this matter local conditions will always govern the precise nature of the treatment used. A close study of the mechanisms by which current methods of treatment operate and of the various factors affecting the efficacy of these methods seems to offer hope of advancement.

"The sedimentation tank is an effective piece of apparatus performing a simple operation. In treating tank effluents, non-settling particles, sludge-forming materials and organic solutes have to be considered. The percolating filter is limited in its effectiveness by its inability to deal rapidly with dispersed particles which tend to choke the bed. Bio-flocculation affords a successful method of reducing the tendency of dispersed particles to clot on the medium of the filter, but its efficiency is limited by the tendency of activated sludge to 'bulk' and by the necessity of reactivating the sludge. If the clotted sewage dispersate could be effectively separated from the active sludge, the production of rapidly-settling artificial sludges might well prove practicable, not only in the bio-flocculation process but in the activated sludge process. Before such a step can be taken, it is important to learn precisely what is happening in the processes themselves. To rid tank effluents of their dispersed materials would be to increase enormously the utility of the percolating filter. 'Chemical' precipitation offers an almost unexplored field. Here the requirements are at least simple: to reduce the charge and hydration on the dispersates of sewage without interfering with their subsequent biological oxidation. If these requirements could be satisfied at reasonable cost, the great objection to precipitation methods (namely, the difficulty of disposing of a voluminous sludge) would disappear.

"The disposal of sludge is a major problem in itself. Where simple dewatering and subsequent dumping is feasible, the process of anaerobic sludge digestion is itself satisfactory. Dewatering is in any case a chemical operation, surrounded by physical difficulties which at the moment are to some extent surmounted by the biological process in use. The length of the operation is a major factor contributing to its cost; it is possible that straightforward chemical attack would solve the problem just as well, but before such an attack could be made a study of the physical properties of the sludges is necessary. Whatever the method of dewatering used, the obstacle to the ultimate disposal of the sludges by useful burning lies in the extent and chemical nature of their ash constituents. The removal of these ash constituents would be an advantage."

C. C. Ruchhoft

SEWAGE DISPOSAL ABROAD

By J. M. Antill

The Surveyor, 91 (Feb. 26, 1937), 341–342

This is an abstract of an article describing various sewage disposal installations in continental Europe. The Henry process, used largely in Belgium and considered successful, consists of chemical precipitation with finely ground lime and clay, using a detention period of 8–10 hours. The major departure from conventional processes, which may be applied to any sludge, consists in treating the sludge with a starch solution and caustic soda, the starch solution previously having been frozen. In one installation, the treated fresh sludge is concentrated in a Dortmund type tank, then flows directly to a centrifugal dewatering machine which gives a cake of 16–20 per cent moisture content.

Compared to English practice, German installations provide less treatment and smaller detention periods, due to large streams generally and the greater dilution afforded. This same tendency was noted in the proposed scheme of sewage treatment for Paris, France.

High rate, fully enclosed trickling filters with forced ventilation, developed by Dr. Pruss in Germany, are operated at four times conventional rates and give freedom from the nuisances associated with trickling filters. Filter depths are greater and the best arrangement for filter stone is considered to be 3″ material for the bottom 3 feet, 3″–4″ material for the top 2 or 3 feet, and ¾″–1″ material in between. Plants of this type are in operation at Holzwickede in the Emscher district and in South Africa.

R. W. Kehr

PROCESSES IN THE DIGESTION CHAMBER OF IMHOFF TANKS

By Dr.-Ing. Husmann

Gesundh.-Ing., 58 (1935), 739

It is commonly believed that no interchange of sewage and sludge liquor occurs in Imhoff tanks. The CO_2 content of gas from Imhoff tanks averages 20–25 per cent as compared to 30–35 per cent from separate sludge digestion tanks. The explanation for this is that the supernatant liquor of separate digestion tanks is changed very slowly. As the gas formed during digestion passes through the liquor the CO_2 is dissolved until saturation is reached and the remainder of the CO_2 passes through.

In two-story tanks some of the sewage enters the digestion chamber as the sludge liquor leaves it and in this way the liquor over the sludge is frequently renewed. Although this exchange of liquid is not enough to affect the freshness of the sewage, a larger amount of CO_2 is dissolved and consequently the amount of CO_2 in the gas is less than from separate digestion tanks.

Experiments made in a series of four Imhoff tanks, each unit of which had three tanks with a common settling chamber in which the direction of flow could be reversed, showed that the average CO_2 content of the gas was:

Inlet tank	5.6%
Center tank	19.2%
Effluent tank	18.3%

There was much less CO_2 in the gas from the first tank than from the other two because of solution in the renewed liquor. That it was not caused by poor digestion is shown by the fact that more CO_2 is formed during acid digestion. When the flow was reversed the CO_2 from the first tank increased, so that in eight days it amounted to about 18.8 per cent. In the center tank the CO_2 remained nearly constant at about 24.2

per cent and in the third tank decreased to about 6.5 per cent. Since this rapid change cannot be caused by biological processes it may be assumed that it is due to replacement of sludge liquor by sewage.

G. P. EDWARDS

THE EFFECT OF IRON AND ALUMINUM SALTS ON THE ACTIVATED SLUDGE PROCESS

BY DR.-ING. NESMEHANOFF (Moscow)

Gesundh.-Ing., **58** (1935), 471

In experiments made to determine the effect of iron and aluminum salts on the activated sludge process, amounts of iron and aluminum salts varying from .0087 to 0.5 grams of pure metal per liter were added to mixtures of sewage and sludge. The amount of air added and the temperature were the same in each tank and the ease of filtration, oxidation, ammonia nitrogen and the pH were determined. Three liters of sludge, to which 4.5 grams of ferrous sulphate had been added, and a control were aerated continuously for 65 days. The sewage liquor was changed at intervals of one to three days. At the end of the aeration period it was impossible to detect any difference in the two sludges. Four tanks of sludge, to which 0.05 to 1.0 gram of ferric chloride had been added, and a control were aerated. Fresh sewage and an amount of iron equal to the initial dose were added from time to time. Because of hydrolysis of the iron salt the pH dropped below 5.3, reducing the activity of the sludge. Aluminum salts which were added to the sludge behaved similarly to the iron salts. Results of the experiments indicated that the addition of iron or aluminum salts cannot be considered as an effective means for increasing the activity of activated sludge.

G. P. EDWARDS

THE SEWAGE FROM THE TANNERY CITY BACKNANG

BY ARCHITECT WIMMER

Gesundh.-Ing., **58** (1935), 542

When it became necessary for the leather industries to purify their wastes it was decided to treat the industrial wastes and domestic sewage in a municipal plant. The wastes from the larger tanneries have been discharged into the Murr River. Since no reliable information as to the amount of sewage and waste was available, measurements were necessary. During the summer of 1934 measurements were made of the sewage from about one-third of the 11,000 inhabitants of Backnang and from about 90 per cent of the waste from the tanneries. A sharp-edged, aerated weir, over which the sewage flowed freely, was placed at the end of a measuring channel about 33 feet long and about three feet wide. At the proper distance from the weir an automatic recording gauge was installed. In addition to the flow measurements, samples were collected every half hour for determination of settleable solids, temperature, pH and hydrogen sulphide. On an average daily sample the moisture and volatile matter in the sludge was determined and the oxygen consumed of the sewage was measured.

From the measurements it was evident that the flow of sewage was entirely dependent upon the method of operation of the industries. The night flow was very small except when the tanneries were operated at night. The sewage flow increased rapidly with the beginning of work at 7 A.M., decreased during the noon hour, increased again during the afternoon and decreased again after 5 P.M. For several hours in the morning the flow was more than 52 gallons per second and the average flow from 7 A.M. to 7 P.M. was 45 gallons per second. The total flow was about 2,245,000 gallons, of which about 90 per cent was industrial waste and 10 per cent domestic sewage. The plant was designed for a flow of 58 gallons per second.

With a two-hour detention period, the settleable solids averaged 85–90 c.c. per liter and varied between 4 and 200 c.c. per liter during the twelve hours from 7 A.M. to 7 P.M. Accordingly, with a two-hour detention period, about 24,700 cubic feet of sludge per day with a moisture content of 97.7 per cent are to be expected. The sludge contained, on an average, 55 per cent organic and 45 per cent inorganic material.

The pH, which averages between 8 and 9, does not permit sludge digestion. Occasionally the sludge was sterile.

Although the main sewer runs to the treatment plant, either on top of the ground or with very little cover, there is little danger of freezing because of the chemicals contained in the sewage.

G. P. EDWARDS

EXPERIMENTS ON PURIFICATION OF PACKING-HOUSE WASTES AT MASON CITY, IOWA

MAX LEVINE, F. G. NELSON, AND ELMER DYE

Iowa Engineering Experiment Station Bulletin 130, February, 1937

An activated-sludge plant treating packing-house wastes was observed for about nine months, after having been reconditioned in an attempt to improve its biological purification efficiency. Reductions of B.O.D. during this period were 54.8 per cent. Experimental activated-sludge units operated on a fill-and-draw basis showed an extremely high purification efficiency, and the poor results of the full-sized plant are attributed to the marked fluctuations of the wastes, both in concentration and in volume. These fluctuations upset the delicate equilibrium which is necessary for successful operation of an activated-sludge plant.

Summary of Reduction in B.O.D. by Various Filter Units

Unit	Description	Rate, m.g.a.d.	B.O.D., p.p.m.		B.O.D. removed	
			Applied waste	Effluent	Pounds per acre	Pounds per acre-ft.
A	Various filling materials 6 ft. deep	1.0	908	44–65	7,040–7,200	1,173–1,200
B	Same as *A*	1.5	758	25–48	8,850–9,150	1,475–1,525
C	Cinders 3 ft. deep	4.0	650	289	12,000	4,000
D	*C* and settled		650	258	13,030	4,343
E	Effluent *D* on 8 ft. fine rock or dolomite	3.0	258	42	5,400	675
F	Effluent *D* on 8 ft. fine or coarse rock	1.0	258	15–22	1,967–2,020	246–253
G	Coarse rock, 10 ft. (aerated)	7.0	929	549	22,100	2,210
H	*G* and settling		929	465	27,000	2,700
I	Effluent *H* on 8 ft. cinders	3.0	465	29	10,900	1,362
J	Effluent *H* on 8 ft. gravel	3.0	465	57	11,100	1,262

Experimental filter units were operated to determine efficiencies of various filling materials and dosing rates with single and double filtration. By double filtration on a deloggable, washable 3-ft. filter, followed by settling and filtration on 8-ft. filters, very high degrees of purification (as indicated by reductions in B.O.D. and by nitrification) were obtained. Primary filtration at 4 million gallons per acre per day (m.g.a.d.) and secondary filtration at 3 m.g.a.d. yielded effluents of 42 p.p.m. B.O.D. for raw waste having a B.O.D. of 650 p.p.m. (over-all reduction of 93.5 per cent). With secondary filtration

at 1 m.g.a.d., overall reductions of 96.6 to 97.8 per cent were obtained. The effluents were very highly nitrified, containing 20.8 to 24.4 p.p.m. of nitrates at 3 m.g.a.d. and 38.8 to 41 p.p.m. of nitrates at 1 m.g.a.d.

From 1,173 to 4,343 lb. B.O.D. were removed per acre-foot by primary filtration and 246 to 1,362 lb. by secondary filtration. The B.O.D. load removed per unit volume of filter varied directly with the concentration and rate of application of the waste and varied inversely with the depth of filter.

Biological digestion of packing-house sludge and the sloughings from filter units yielded 11 to 14 cu. ft. of gas per pound of volatile solids in the sludge. Ninety per cent of the gas was evolved during the first 25 days of digestion. Experiments on high-temperature digestion showed an increased rate of decomposition but, because of the nature of the residual sludge and supernatant liquid, high-temperature digestion did not appear feasible.

While the experiments were carried out on small-scale units, the results, which showed the effectiveness of double filtration for treating packing-house wastes, were later borne out in a full-sized plant designed on the basis of this research.

Author's Abstract.

BEET SUGAR FACTORY WASTE TREATMENT

By E. F. Eldridge

Report on Sanitary Engineering Projects, 1936. Michigan Engineering Experiment Station Bulletin No. 71.

Following satisfactory operation of a 100,000 g.p.d. experimental plant for treatment of beet sugar factory wastes during the 1935 season, it was decided to build and operate a full scale unit capable of treating 1 to 1.5 M.G.D. during the 1936 season. This project was made possible through the co-operation of ther Farmers and Manufacturers Beet Sugar Association, the Michigan Stream Control Commission and the Michigan Engineering Experiment Station. The objectives sought under this project were: (1) to compare the removal of solids and B.O.D. obtained by the full size plant with results obtained with the experimental plant; (2) to obtain additional information on grit and grit collection; (3) to secure further data on sludge volumes, concentration and disposal; (4) to determine details of design for future construction of similar units; (5) to determine power requirements and costs; (6) to attempt vacuum filtration of sludge on a larger scale than was possible during 1935.

The treatment plant consisted of a grit chamber, 3 feet wide and 25 feet long, equipped for continuous grit removal; a mixing flume 25 feet long and 15 inches wide with a slope of about 12 inches, in which the wastes were mixed with lime from a dry feed machine; a coagulation tank with horizontal revolving paddles and a rectangular settling tank equipped with mechanical scrapers for sludge removal. A vacuum filter, 6 ft. in diameter by 6 ft. long was ordered for drying the sludge from the settling tank. Strikes in the manufacturing plant made it necessary to cancel this order and a second hand filter was obtained. This filter was in poor condition and as a consequence much trouble was experienced in its operation. A wood sludge storage tank was also erected.

The plant was operated for seventy-three days from October 10 to December 21, under the following operating procedures: (1) plain sedimentation of factory waste at 1 and 1.5 M.G.D.; (2) coagulation of factory waste with lime and sedimentation at 1 and 1.5 M.G.D.; (3) sedimentation of a mixture of factory waste and 2.4 to 4.3 per cent Steffens waste at 1 and 1.5 M.G.D.; and (4) coagulation of the mixed wastes and sedimentation at 1 and 1.5 M.G.D. Samples were collected every 30 minutes from the influent and effluent, composited over a 12 hour period and analyzed for total solids, suspended solids, five-day B.O.D., pH and occasionally chlorine demand. Measurements were made of the volume of sludge produced and it was analyzed for moisture content. Occasional measurements and analyses of grit were made. It was found that the grit chamber was not long enough to remove all of the grit, particularly at 1.5 M.G.D. flow and that the grit accumulated in the coagulating tank. This trouble prevented operation of the plant at 2 M.G.D. as had been originally planned.

Detailed tables of results for each run and tables of averages for the various operating procedures are given, but the essential data are summarized in the following:

Comparison of Average Results Obtained with Different Rates of Flow

Determination	1 M.G.D.			1.5 M.G.D.		
	Inf. p.p.m.	Eff. p.p.m.	Rem. %	Inf. p.p.m.	Eff. p.p.m.	Rem. %
Plain sedimentation of factory waste						
Total Solids	3,026	1,426	53.1	4,252	1,873	55.9
Suspended Solids	1,624	93	94.4	2,654	114	95.7
5-day B.O.D.	512	253	50.6	442	212	51.9
Coagulation of factory waste						
Total Solids	2,697	1,438	46.7	2,630	1,312	50.1
Suspended Solids	1,436	86	94.2	1,444	77	94.6
5-day B.O.D.	480	221	54.1	382	174	54.4
Mixture of Steffens & factory waste						
Total Solids	4,201	1,843	56.2	4,328	1,878	56.6
Suspended Solids	2,231	64	97.3	2,598	80	96.9
5-day B.O.D.	658	246	62.3	722	219	69.9
Coagulation of mixture of Steffens and factory waste						
Total Solids	3,640	2,315	36.5	4,788	2,285	52.3
Suspended Solids	1,752	15	99.2	1,878	27	98.4
5-day B.O.D.	575	244	57.5	673	264	60.8

Average Sludge Data Obtained with Different Rates of Flow

Rate	1 M.G.D.	1.5 M.G.D.
Plain sedimentation of factory waste		
Volume, gallons per m.g.	7000	5970
Volume, cubic feet per m.g.	934	798
Moisture, per cent	85.0	79.8
Dry solids, pounds per m.g.	8750	10050
Coagulation of factory waste		
Volume, gallons per m.g.	7190	6970
Volume, cubic feet per m.g.	960	930
Moisture, per cent	82.3	81.8
Dry solids, pounds per m.g.	10580	10550
Mixture of Steffens and factory wastes		
Volume, gallons per m.g.	7070	6690
Volume, cubic feet per m.g.	942	892
Moisture, per cent	85.4	79.7
Dry solids, pounds per m.g.	8610	11500

It was found that the full scale plant showed a greater efficiency in removal of suspended solids and B.O.D. than did the experimental plant in 1935, and that the sludge withdrawn had a much lower moisture content in the larger plant.

Owing to the poor condition of the vacuum filter and its late installation, results obtained in dewatering the sludge were very unsatisfactory. Enough runs were made, however, to show that a very good filter cake could be obtained with a lime-conditioned sludge. The lime requirements are from 50 to 80 pounds per 1,000 gallons of factory waste sludge and from 20 to 50 pounds per 1,000 gallons of sludge from the Steffens and factory waste mixtures. An average of 4.5 gallons of sludge per square foot of filter surface per hour was filtered with a resultant cake moisture of less than 50 per cent.

The major conclusions drawn are: (1) About 95 per cent of the suspended solids and over 50 per cent of the B.O.D. may be removed from factory waste by plain sedimentation. Coagulation with lime does not increase the efficiency sufficiently to warrant its use. A coagulation period of 20 minutes and a settling period of 80 minutes were just as effective as periods of 30 minutes coagulation and two hours settling.

(2) Mixing Steffens and factory wastes in plant proportions resulted in the removal of about 97 per cent of the suspended solids and an average of almost 70 per cent of the B.O.D. Coagulation of the mixed wastes with lime is not warranted. Detention periods of 20 minutes coagulation and 80 minutes settling are sufficient.

R. S. SMITH

SPRAY DRYING OF STEFFENS WASTE

BY E. F. ELDRIDGE AND F. R. THEROUX

Report on Sanitary Engineering Projects, 1936. Michigan Engineering Experiment Station Bulletin No. 71.

Experiments on the spray drying of Steffens waste from a beet sugar factory were made at Blissfield, Michigan, under a cooperative agreement between the beet sugar interests and the Engineering Experiment Station in an endeavor to find a feasible and economically possible method for the elimination of Steffens water as a waste product. A minor objective was the possible recovery of valuable products such as fertilizer material.

Numerous attempts have been made to evaporate Steffens waste, generally by evaporation in triple-effect evaporators. Spray drying of this waste by means of waste flue gases would result in a recovery of waste heat, eliminate at least a considerable portion of a troublesome liquid waste and yield a dry product without the difficulties previously encountered. Theoretical considerations indicated that the waste flue gases of the average factory would evaporate about two-thirds of the Steffens water produced, assuming utilization of 50 per cent of the waste heat.

The experiments were conducted in a room 70 feet long and 30 feet wide on the second floor of a brick and concrete building adjacent to the breaching to the boiler room stack. A circular conduit 55 inches in diameter with a damper and sliding air inlet was constructed from the breaching to the suction side of a steam driven fan. A 39 inch conduit led from the fan to a square conduit across the end of the building. The latter conduit had 6 inch by 12 inch ports on 12 inch centers provided with sliding covers which served as hot gas outlet openings from the conduit. Steffens waste was piped to two 50 gallon drums and then pumped at a pressure of 1,000 pounds per square inch to spray nozzles located over the exhaust ports in the conduit. A 30×30 foot drying room was formed by hanging a galvanized iron partition from the roof to within three feet of the floor. The remainder of the room was used as a settling chamber for the dried material. A galvanized iron outlet conduit carried the waste gases to a stack.

Considerable soot and fine cinders accumulated in the conduits and in all parts of the room. This was not seriously objectionable since it apparently acted as a dryer and seemed to decrease the hydroscopic character of the dried Steffens solids. Considerable trouble was caused by the spray nozzles. One set would not stand the necessary high pressure and all types required cleaning about every eight hours, necessitating an arrangement to allow the removal of individual nozzles without a shut down. Dipping in weak hydrochloric acid was found to be the best method of cleaning clogged nozzles. It was

found that some storage for liquid waste should have been provided to allow continuous operation. The average results for the various runs are given in the table below:

Date (1936)	Time Operated Minutes	Steffens Sprayed Gallons	Gases Million Cu.ft.	Gas Temp., Deg. F.			Calculated Heat Loss from Gases Million BTU	Theoretical Heat Req'd for Drying Million BTU	Efficiency Per Cent
				Inlet	Outlet	Drop			
Oct. 23	255	1,100	4.08	407	221	186	8.69	9.17	100
24–25	870	3,500	13.92	381	207	174	28.30	29.19	100
30	615	3,000	9.20	499	233	266	25.30	25.02	98.8
31	330	1,500	2.25	515	220	295	6.77	12.56	—
Nov. 7–8	1,080	3,700	17.45	560	307	253	43.00	30.86	72.0
11–15	582	2,200	5.82	507	212	295	17.50	18.35	100
19–22	2,890	10,830	37.57	445	203	242	99.50	90.32	90.5
23–26	2,070	8,300	31.05	341	151	190	73.30	69.22	94.4
27–28	1,125	3,500	16.87	435	181	254	47.40	29.19	61.8

It is concluded that Steffens waste can be successfully dried in this manner. The heat utilization is about as anticipated but it may be possible to use lower outlet temperatures which would result in drying a larger volume of Steffens water with the waste heat available. It is felt that it would be desirable to attempt the use of some type of collector for the dried material, either a cyclone separator or a mechanism to automatically scrape the dry material from the floor.

R. S. Smith

THE DESIGN AND OPERATING RESULTS OF A TYPICAL MILK WASTE FILTER

By E. F. Eldridge

Report on Sanitary Engineering Projects, 1936. Michigan Engineering Experiment Station Bulletin No. 71.

The milk waste treatment plant described was constructed at the Sheridan condensery of Libby, McNeill and Libby in accordance with the recommended design of the Michigan Experimental Station. The plant consists of a storage tank 20 feet long, 15 feet wide and with an average water depth of 4.5 feet, equivalent to about one-half of the estimated volume of waste. The waste is pumped from this tank to the rotary distributor of a covered trickling filter 50 feet in diameter and 8 feet deep. This filter is underdrained by half tile on 2 foot centers. The filter effluent flows to a settling tank 20 feet long, 5 feet wide and 4.5 feet average depth.

Rate of Application of Waste to Filter

Series Number	Total Volume of Waste (Gallons)	Time of Factory Operation (Hours)	Time of Filter Operation (Hours)	Rate of Application (Gal./sq.ft./hr.)
1	21,503	6	11	1.0
2	25,697	9	13	1.0
3	20,370	9	10.5	1.0

Analysis of Composite Samples

Series Number	Sample	Total Solids		Suspended Solids		5-day B.O.D.	
		P.p.m.	Per Cent Reduction	P.p.m.	Per Cent Reduction	P.p.m.	Per Cent Reduction
1	Raw	——	——	——	——	640	——
	Filtered	——	——	——	——	280	56.2
	Final	——	——	——	——	140	78.1
2	Raw	1648	——	572	——	1180	——
	Filtered	1256	23.7	160	72.1	120	89.8
	Final	1276	22.5	56	90.2	104	90.8
3	Raw	2004	——	520	——	1140	——
	Filtered	1768	11.5	780*	——	270	76.3
	Final	1224	38.8	160	69.2	150	86.8

* Filter Unloading.

Early in the fall of 1936, flow measurements were made and samples collected for three days at intervals of a week. The filter shows a very high efficiency in removal of B.O.D., but this is undoubtedly due to the low rate of dosage. The filter was designed to take care of anticipated expansions of the factory and has a capacity of several times the volume of waste treated.

R. S. Smith

THE ECONOMIC IMPORTANCE OF WASTE TREATMENT TO THE INDUSTRIES

By Michael J. Blew

Industrial and Engineering Chemistry, News Edition, **14** (November 20, 1936), 445–46

After discussing various factors in waste treatment, the types of effluents, and the alternatives in disposing of waste from many industries, the following cases where industry has directly benefited by measures to alleviate stream pollution were presented:

Paper Industry.—By installing save-alls and recirculating the white water, paper industries have been able to reduce the pulp loss to practically nothing. The higher the grade of paper stock being produced, the greater the loss that may be encountered in the process when only a few parts per million of pulp are permitted to escape. The value ranges from $20 to $65 per ton of pulp, practically all of which can be recovered by recirculating the white water. In this instance, success was achieved by chlorine or chlorine-ammonia treatment of the white water to prevent the development of fungus growths. This process can be operated on practically a closed basis with a saving of pulp and power and reducing the pollution load about 70 to 90 per cent.

Photographic Chemicals.—The waste from the manufacture of films contains as much as 3 ounces of silver per ton of waste water. This can be recovered by zinc oxide and lime, making the process profitable.

Mercerizing.—A process is in effect recovering 97 per cent of the caustic soda from a mercerizing plant. This is one of the meanest of trade effluents, and can be treated by this process at a profit. Similar wastes could be treated in a like manner with a saving of chemicals and tremendous benefit to the rivers.

Wool Scouring.—This plant installed a semi-closed system to utilize the water from the end of the scouring train after treatment by centrifugals. The effluent was reduced 90 per cent in volume and also in pollution load. The water consumption was reduced

to about 10 to 15 per cent of the original, this being necessary to compensate for loss by steam, spillage, and as make-up water to maintain the dissolved solids in proper balance. The sludge was treated to recover the grease. With grease worth 6 to 7 cents per pound, this process was self-supporting. In Germany, this sludge is filtered and the cake extracted with benzine. Savings consisted in fuel for heating the scouring water, soap and detergents, water pumping charges, and stock losses through the effluent.

Grease Rendering.—This plant cooled its waste liquids, skimmed them, and recovered sufficient grease to pay for the treatment. It recovers from 60 to 75 per cent of the grease and renders its effluent to the sewer unobjectionable.

Laundry.—This laundry installed a trap and screen and recovered enough linen to pay for the process. The effluent was then treated with domestic sewage without difficulty. There are instances where sufficient linens are recovered on the screens of disposal plants to warrant conducting sales. These losses are largely from hotels and restaurants.

Distillery Slop.—Pollution from this source may be almost entirely avoided by evaporating the slop. The entire solid content can be recovered for cattle food and the water vapor from the evaporators returned to the mash tanks.

Carbonizing Plant.—This wool scouring plant added a carbonization process. The effluents from the two processes were combined and trapped. The traps were skimmed and screened, recovering sufficient wool to make it profitable. The effluent was alkaline, and sufficiently clean to mix with domestic sewage in the sewerage system.

Plant Co-operation.—Another interesting case is that of two meat packers working in harmony with another industry. The packers dry the blood and grease together and sell it for about 2 cents per pound to the third industry, which is profitably engaged in making glycerol and stearic acid.

A storage battery plant with a strong acid waste is located near a silk dyeing plant with an alkaline waste. Both effluents are deleterious to the sewer structure and to sewage treatment. They are combined and mixed with domestic sewage with no ill effects.

Heat Recovery.—Another plant has installed copper coils in its settling tank and recovers sufficient heat to cover the cost of treatment. There are many instances where heat recovery can be used advantageously.

Sufficient importance is rarely attached to the composition of water used in industrial plants. If the supply is abundant and reasonably economical, it generally satisfies the engineer. The possibilities of deleterious and destructive chemicals in the water are often entirely overlooked.

Canneries have had their products rendered unmarketable by chemical tastes in their water supply. Dyeing, textiles, laundries, and wool-scouring plants require water free from iron, manganese, acids, and alkalies. Excessive hardness gives rise to wastage of soap and increased cost for water-softening. The precipitate of calcium and magnesium soaps forms a greasy curd that sticks to the cloth, increases the labor of cleaning, and shortens the life of the fabric. Excessive hardness causes wastage of tanning material, and uneven shades in the leather. Waste matter in water can cause priming, foaming, and scale in boilers, and possibly corrosion—all aggravated by waste in river water.

Apparently the plan of attack should be: to increase the development and installation of closed systems, which can be used by many places that at present decry the idea; to develop new and better processes; to institute intelligent research on the utilization of by-products; to separate waste from drainage and storm water to reduce the cost of effluent treatment; to combine wastes, taking advantage of their differences in chemical character to render them innocuous or less harmful, and to minimize their deleterious and destructive effects; to utilize heat in effluents by heat exchanges; to develop better machinery; to utilize cheaper construction in plant design. There is probably no reason for the construction of elaborate concrete tanks when steel can be employed to better advantage and at a much lower cost. Steel has been used in water works for years, and undoubtedly can be used in sewage and trade-waste work with equal success. The present method of construction, erection, and welding in place makes steel a desirable material for treatment tanks.

Many industries in the past had the wrong attitude toward stream pollution, but

are slowly changing from the defensive to the aggressive for the protection of their own interests. It is inevitable that eventually they will force each other and also municipalities to adopt stream protective measures.

C. C. RUCHHOFT

SOME ECOLOGIC FACTORS AFFECTING THE DISTRIBUTION OF THE PROTOZOA

BY JAMES B. LACKEY

Abstract of a paper prepared for the Limnological Society of America, Atlantic City, N. J., December 30, 1936.

The careful analysis of 235 fresh plankton samples taken over a period of ten years shows the presence of 348 species of protozoa, excluding about 5 per cent which were not identified, and including a few tentatively accepted as new species. One of the sample groups comprised marine samples and only those protozoa appearing in one or more of the remaining seven fresh water groups are included in the marine group.

By a study of these accumulated data and references to a selected group of 38 articles by other workers it is concluded that the environmental factors regulating the distribution of protozoan species are almost wholly unknown, and that present ecologic classifications of more than a very few species should be accepted very cautiously. A table is given showing the distribution of the 348 species among the eight habitat types, and 12 species are shown to occur in all eight. In the first three, clean fresh water habitats, 41 species occur, and in the last four containing, or made up of sewage, 57 species occur. Of the 98 species which have been found in Imhoff tanks, 88 occur in grossly polluted streams. The numbers of species are distributed as follows:

	Samples	Species
Stagnant, clean waters	70	289
Open waters (plankton protozoa)	20	108
Tree holes	25	103
Marine samples	40	68
Polluted streams	40	148
Imhoff tanks	50	98
Trickling filter	50	136
Activated sludge chambers	40	99

Of the 348 species only 57 occurred as much as 33 per cent of the time in any one habitat type. The common occurrence of those 57 species is shown below (designated by letter "C"):

In evaluating this table, it must be borne in mind that it is not the chance occurrence of an organism in a habitat type but its frequent recurrence there which is significant. Thus *Amoeba proteus* was also found in four other habitat types, viz., columns 2, 5, 7 and 8, but only a few times in each, and *Arcella vulgaris* was found in all situations except the ocean. Such use of the accumulated data shows that the following protozoa are especially valuable as indicating gross pollution: *Antophysa vegetans, Monas minima, Cicomonas termo, Pleuromonas jaculans, Tetramitus decissus, T. pyriformis, Trepomonas agilis, T. rotans, Carchesium lachmanni, Glaucoma scintillans, Paramecium caudatum, Stylonichia pustulata* and *Vorticella microstoma.* The evidence warrants such an interpretation on finding numerous individuals of any, some, or all of the above species in a given sample, or of noting their frequent recurrence even in small numbers, at a sampling station.

Now it is noteworthy that "the Euglenas and their allies" are not found in this group. This study, however, is a qualitative one; the Euglenas are most common in the first type of habitat. Nevertheless, a quantitative study probably would show that *Euglena viridis* could be used as an indicator of pollution.

Species	Stagnant, Clean Waters. (1)	Open Waters, Plankton Types. (2)	Tree Holes. (3)	Marine Samples. (4)	Polluted Streams. (5)	Imhoff Tanks. (6)	Trickling Filter. (7)	Activated Sludge Chambers. (8)
Amoeba proteus	C							
Amoeba striata							C	
Arcella vulgaris	C						C	C
Centropyxis aculeata							C	C
Chlamydophrys stercorea							C	
Cochliopodium bilimbosum							C	
Hartmanella hyalina					C	C	C	C
Nuclearia simplex							C	C
Vahlkampfia albida	C						C	
Vahlkampfia gultula							C	
Vahlkampfia limax							C	C
Anthophysa vegetans					C			
Bodo caudatus						C		
Bodo ovatus						C		
Cercobodo caudatus						C		
Cercobodo longicauda						C		
Cryptomonas erosa	C	C						
Cryptomonas ovata	C	C						
Cyathomonas truncata	C							
Entosiphon sulcatum	C						C	
Endorina elegans		C						
Euglena piciformis	C							
Euglena polymorpha	C							
Euglena sociabilis		C						
Euglena viridis	C							
Gonium pectorale		C						
Mastigamoeba longifilum						C		
Monas minima					C		C	C
Notosolenus orbicularis						C		

The paper shows that low temperatures are not limiting for the number of species, and may not be limiting for numbers of individuals; that seasonal successions are doubtful *per se*, but may be occasioned by attendant factors as an increase of erosion silt due to seasonal rainfall.

The hydrogen ion concentration range of natural waters is shown to be of doubtful importance in the occurrence of 26 species, and the same is true of the chemical make-up of the same series of waters. Food cannot be shown to be a factor in the case of bacterial eating protozoa in sewage plants; it is noteworthy that Imhoff tanks and activated sludge chambers have the lesser numbers of species; both have an abundance of bacteria for food. Oxygen depletion appears to be the limiting factor for the former, and turbulence is a possibility for the latter.

All in all, it appears that very little is actually known of the factors influencing the natural distribution of the protozoa and that a careful study of these factors might provide stream pollution and sewage disposal workers with some very valuable information.

Species	Stagnant, Clean Waters. (1)	Open Waters, Plankton Types. (2)	Tree Holes. (3)	Marine Samples. (4)	Polluted Streams. (5)	Imhoff Tanks. (6)	Trickling Filter. (7)	Activated Sludge Chambers. (8)
Oicomonas termo					C		C	
Oicomonas sociabilis						C		C
Pandorina morum		C						
Peranema trichophorum	C						C	C
Pleuromonas jaculans					C	C	C	C
Tetramitus decissus					C			
Tetramitus pyriformis					C			
Trachelomonas hispida	C							
Trachelomonas volvocina	C	C	C					
Trepomonas agilis					C	C		
Trepomonas rotans					C			
Aspidisca costata							C	C
Carchesium lachmanni					C			
Chilodon cucullulus							C	
Cinetochilum margaritaceum	C							
Cyclidium glaucoma	C	C		C	C		C	C
Epistylis plicatilis								C
Glaucoma scintillans					C		C	C
Halteria grandinella		C						
Lionotus fasciola							C	C
Metopus sigmoides						C		
Microthorax sulcatus			C					
Opercularia spp.							C	C
Paramecium caudatum					C			
Saprodinium putrinum						C		
Stylonichia pustulata					C			
Trimyema compressa					C	C		
Vorticella microstoma					C			C

A QUANTITATIVE STUDY OF THE ELBE RIVER WITH PARTICULAR CONSIDERATION OF THE INFLUENCE OF SEWAGE ON THE PROCESS OF BIOLOGICAL SELF-PURIFICATION

By Theodore Seeler

Archiv. für Hydrobiologie, **28** (1935), 323–356

This is the first of a series of studies of the pollution of German streams. Samples of the Elbe were taken at 5 km. intervals from Madgeburg to its mouth, about 355 km., on a number of trips in 1932–34. Four groups of plankton organisms, phytoplankton, Protozoa, Rotifera and Crustacea were studied quantitatively and results graphically shown in 19 charts. Species and genera were not identified, nor was consideration given to pollution and clear water forms.

The phytoplankton, forms such as Pediastrum and Scenedesmus, was most abundant and showed the greatest effects attributed to sewage. Madgeburg with 308,000 people empties its sewage from a clarifying tank (klaranlage) into the river, and a sharp decline in the number of organisms results. Crustacea and Rotifera were greatly harmed

and disappeared in part; the few Protozoa, characterized mostly by Vorticella, increased slightly; and the algal cells soon regained their high numbers. These effects were visible for 120 km., almost to Wittenburg, but at the end of this zone algal cells were about 12,500 per c.c., and Rotifera and Crustacea were increasing in numbers.

The sewage of Wittenberg's 20,000 population again decreased numbers, but the slower flow and diminished pollution caused a more rapid increase and a greater plankton population was present between Wittenberg and Hamburg, until numbers were relatively high. This 325 km. stretch of the river is stable in its behaviour and more uniform in its plankton content, than the river below Hamburg.

At Hamburg, however, the tidal zone begins and besides domestic sewage much industrial sewage enters the river. A sharp drop in the plankton occurs here, but there is normally a quick recovery until the brackish water zone begins some 30 km. below the city.

However, the Elbe was very low in June, 1932, and with the ebb and flow of the tide, the sewage was carried back and forth, until with excessive pollution the plankton Algae began to die and reached very low numbers. The dissolved oxygen curve followed a similar procedure and the zooplankton died, until very low numbers were left. Even fish were affected. Recovery of the phytoplankton eventually began downstream and moved up; the oxygen increased, and by early July a more normal plankton was present.

The paper shows clearly the quantitative effects of sewage on plankton, and the distances its effects are visible. It also shows effects indirectly due to sewage and the possibility of an unstable condition where tide flow is encountered in a polluted stream. Cross sections of the stream show the tendency of organisms to remain on the side they enter, or on which they develop, for long distances.

JAMES B. LACKEY

VENTURI FLUMES FOR SEWERS

BY H. K. PALMER

Water Works and Sewerage, 83 (September, 1936), 322–324

It is more difficult to measure sewage flow than water flow because solids tend to settle when the velocity is checked and because pipes and conduits are usually deeply buried. This special Venturi flume overcomes the drawbacks of the Parshall meter for sewage because a float is set in the channel above the flume. This type can be used in an already constructed sewer, and only a single depth measurement is necessary if the throat is properly proportioned to the size and grade of the pipe. The Bernoulli principle is used, *i.e.*, the energy of each pound of water flowing is equal to the pressure plus the velocity head, and is constant except for friction and eddy losses.

The elevation of liquid where it is measured (Y) equals the elevation of the energy head in the throat (E), minus the velocity head at the point of measurement, or $Y = E - V^2/2g$. The elevation of the energy head in the throat must exceed that in the conduit below the flume.

For a rectangular flume, $Q = 3.09\ bE^{1.5}$
For a triangular flume, $Q = 2.297\ pE^{2.5}$
For a trapezoidal flume, $Q = 3.06\ (b + 0.72\ pE)\ E^{1.5}$

Q = flow in cubic feet per second,
E = energy head in feet above throat invert,
b = bottom width of flume,
p = side slopes of flume, horizontal/vertical.

Under ordinary conditions the error is felt to be about 2 per cent. The grade of the sewer may not be so steep that the normal flow of liquid is at less than the critical depth.

JAMES H. LE VAN

SEWAGE DISPOSAL FOR THE NATION'S CAPITAL

By Frank A. Marston

Engineering News-Record, **118** (March 25, 1937), 431–436

Construction work has been practically completed on the 130 m.g.d. sewage treatment plant for the District of Columbia. The new plant, to be put into operation this spring, provides plain settling with separate sludge digestion and includes such features as aeration tanks for grease separation, the generation of electric power by use of sludge gas and elutriation of digested sludge prior to dewatering on vacuum filters. The design of the plant is predicted on an investigation of the sewage disposal problem of the District of Columbia made in 1933 by a board of sanitary engineers composed of H. P. Eddy, S. A. Greeley and the late J. H. Gregory. This board recommended: (1) that a sedimentation process be used during the six cool months of the year, and (2) the adoption of activated sludge treatment during the remaining months. The present plant, intended as the first step toward fulfillment of these recommendations, is designed to serve a population of 650,000, estimated for 1950. The plant will effect a 45 per cent removal of suspended solids and a 35 per cent reduction of B.O.D. Sewage will flow by gravity to the plant, which is on the east bank of the Potomac River opposite Alexandria, Va.

At the plant the sewage will be lifted 20 feet by four pumps with capacities varying from 40 to 80 m.g.d. The pumps discharge through individual conduits into an influent channel common to all eight grit chambers, each 10 ft. wide, 80 ft. long, with an effective operating depth of 2.5 ft. Deposited grit will be scraped to the inlet ends, elevated by screw conveyors and discharged into buckets which will be dumped either into trucks or a storage hopper.

The grit chambers are covered and provision is made for drawing in air from the head house and discharging it through the stack at the power plant. From the grit chambers the sewage passes through a 9 ft. × 4.5 ft. venturi meter with the flow measurements electrically transmitted to indicators in the pumping station and grit chamber head house and to a register-indicator-recorder in the administration building. Between this venturi meter and the settling tanks are three aerated grease-separating tanks, each 15 ft. wide, 78 ft. long and 15.5 ft. maximum water depth, with two rows of diffuser plates along one side. These grease-separating tanks are covered and the air used for agitation will be drawn out through covered channels leading to the settling tanks and discharged through the power plant stack. With all three tanks in operation, the detention period will vary from 3 to 9 minutes, with an average of 4 minutes.

There are 12 settling tanks, providing an average detention period of 2 hours, arranged in groups of four, around control houses. These tanks are 106 ft. in diameter with an average effective depth of 14 ft. and are of the central feed, peripheral overflow type, provided with clarifier mechanism and skimming baffles. Scum will be pumped into the sludge digestion tanks. The sludge pumps are of the duplex plunger type. There are eight digestion tanks, four on each side of an operating gallery, with a combined capacity equivalent to 1.75 cu. ft. per capita. Each tank is 84 ft. in diameter, with a 24 ft. side wall depth and a cone bottom 14 ft. deep. Each tank is provided with a fixed roof for gas collection, hot water heating coils and flushing nozzles around the base of the side wall and at the end of the sludge draw-off pipe. Overflow liquor will be discharged to the influent of the settling tanks. Four sludge pumps are provided to discharge digested sludge to the elutriation tanks, but the piping is so arranged that the pumps may be used for circulation or multiple stage digestion of the sludge. A double lift, water-seal gas holder of 150,000 cu. ft. capacity has been installed.

The digested sludge and elutriating water will be mixed in two aerated mixing tanks with a total capacity of 2200 cu. ft. Normally, river water will be used for elutriation but provision is made for using settled sewage. From the mixing tanks the sludge and water will go to four settling tanks each 16 ft. wide, 60 ft. long and 11.7 ft. average depth and a combined capacity of 50,000 cu. ft., equivalent to the normal daily sludge production plus two volumes of wash water. The settled sludge will be removed by scrapers and pumped to the dewatering plant and the overflow liquid pumped to the inlet of the settling tanks.

The elutriated sludge will be fed to the chemical mixing tanks by a revolving bucket wheel, ferric chloride added in proportion to the sludge flow and mixed by paddles for five minutes. Provision is also made for the addition of lime to the sludge by means of dry feed machines with a capacity of 12.5 lbs. per min. The sludge will be dewatered on four vacuum filters, each 11.5 ft. in diameter, 14 ft. long and with an effective area of 500 sq. ft. The filter cake will be discharged onto a 24-inch belt conveyor and carried to a loading platform for delivery to trucks, storage, or railway gondolas. The filter cake will be taken to Lorton, Va., about 35 miles away, for land disposal.

The gas from the sludge digestion tanks will be used to generate electric power by means of a 1200 H.P., 6 cylinder internal combustion engine direct-connected to a 1000 kva. generator designed to operate in synchronism with the public utility central station or as an independent unit carrying a portion of the plant load.

R. S. SMITH

SEWAGE TREATMENT FOR DENVER

ANON.

Engineering News-Record, **117** (October 15, 1936), 535–539

Construction contracts have been awarded on a 54 m.g.d. sewage disposal plant for Denver, Colorado. The treatment consists of preaeration, coagulation with chlorinated copperas, sedimentation, filtration through rectangular downflow magnetite units and separate sludge digestion. To meet a limit of 40 p.p.m. allowable B.O.D. below Denver, an estimated 12,000 acre feet of water are to be diverted annually from the western slope and used as additinoal dilution for the effluent.

The design calls for shredding of screenings and mechanical grit removal. The bulk of ferric coagulant required is to be manufactured from scrap iron by allowing a .34 per cent chlorine solution a 90 minute reaction period with the scrap iron. Facilities are provided in addition for chlorinating dry fed copperas. The coagulant is added ahead of preaeration and 15 minutes flocculation is provided, then two hours sedimentation. The magnetite filters will operate normally at a rate of 2.68 gallons per sq. ft. per minute and flows in excess of a 4.0 gallon rate are to be bypassed after sedimentation. Wash water will be returned to the preaeration tank. Sludge gas is to be collected and the digested sludge is to be air dried and removed from the sand beds by belt conveyor. Practically all of the diluted plant effluent will be diverted for irrigation within 40 miles of Denver. Of the 130,000 acres under irrigation, 18,000 acres are devoted to intensive truck gardening.

R. W. KEHR

PUBLIC WATER POLLUTION CONTROL IN NEW HAMPSHIRE

BY C. D. HOWARD

Journal New England Water Works Association, **50** (September, 1936), 334–339

The State Board of Health, by means of regulations based on state laws, has authority to prevent any increase in existing stream or lake pollution or to prevent the discharge of wastes, except under approved plans, into any public water not hitherto (1913) polluted. The board is empowered to limit the extent of bathing, boating or fishing on a source of public water supply. Other than institution of proceedings against a public nuisance, or an act of the legislature, there is no authority to require sewage treatment on existing systems. Except in a few instances, the lakes and ponds are clean. ". . . there are grounds for serious question as to the desirability of attempting to clean up such main streams as the Merrimack and the Connecticut Rivers . . . without provision of substantial federal cooperation."

R. W. KEHR

REFERENCES TO SEWAGE LITERATURE

(February–May, 1937)

American City

March, 1937.

"New Sewage Treatment Plant Built to Be Attractive." C. B. Carpenter, pp. 60–62.

"Combined Wastes Disposal Plant at Herkimer, N. Y.," pp. 63–66.

April, 1937.

"Three Methods of Aeration in One Activated Sludge Plant." T. R. Kendall, pp. 63–65.

"New Chemical Treatment Plant for Domestic Sewage and Wastes," pp. 66–68.

Engineering News-Record

February 25, 1937.

"Extension of Sewage Disposal System for Boston," pp. 292–293.

March 11, 1937.

"Large Sewer On Ocean Bottom Has Points of Novel Design," pp. 369–373.

March 25, 1937.

"Sewage Disposal for the Nation's Capital." F. A. Marston, pp. 431–436.

April 8, 1937.

"Severe Damage to Sewer Outfall Caused by Action of Acids," pp. 519–521

Municipal Sanitation

February, 1937.

"St. Louis Discharges Garbage into Mississippi River." F. J. McDevitt, pp. 125–128.

"Recent Developments in Air Diffusion." F. C. Roe, pp. 129–131.

"Incinerator Supplies Power for Sewage Plant," pp. 132–133.

"Stainless Steel in Sewage Treatment." C. G. Snyder, pp. 134–135.

"Grand Rapids Sewage Works Finds Steady Demand for Sludge Fertilizer," p. 141.

"Laboratory Control of Sewage Treatment. VII. The Chemical Analysis of Sewage." F. W. Gilcreas, pp. 145–146.

"Status of Sewage Treatment in the U. S.—South Dakota and Georgia." W. W. Towne and W. H. Weir, pp. 147–148.

March, 1937.

"St. Charles, Ill., Sewage Treatment Plant." C. W. Klassen, pp. 172–175.

"Report on Chicago's Amebic Dysentery Epidemic," p. 175.

"Triturator Performance at Milwaukee." W. B. Marshall and K. C. Merz, pp. 176–177.

"Sewage Treatment Abroad." W. Rudolfs, pp. 179–183.

"Waste Disposal for Greenbelt, Md." F. Schmidt, pp. 186–187.

"Laboratory Control of Sewage Treatment." F. W. Gilcreas, pp. 188–189.

"Sewage and Industrial Wastes Disposal, Indiana and West Virginia." B. A. Poole and E. S. Tisdale, pp. 190–192.

April, 1937.

"New Britain Completes Plant of Guggenheim Type." F. G. Cunningham and H. K. Gatley, pp. 214–220.

"Observations on Sewage Treatment Abroad. Part 2." W. Rudolfs, pp. 221–224.

"Laboratory Control of Sewage Treatment." F. W. Gilcreas, pp. 225–227.
"Status of Sewage and Industrial Wastes Disposal in the U. S." "Kentucky," F. C. Dugan. "Wyoming," L. V. Williams, Jr., pp. 231–232.
"Pointers on Sewer Law." L. T. Parker, pp. 233–235.
"Patent Issued on Sewage Treatment," p. 235.
"Flow Diagrams of Typical Treatment Plants," p. 237.
"Handling Supernatant Liquors at Sewage Treatment Plants," pp. 238, 240.

May, 1937.
"Hazards and Safety Measures at Sewage Works." L. W. Van Kleeck. Part I. Pp. 262–264.
"Modern Cast Iron Sewers." D. W. Johnson, pp. 265–267.
"Grit and Screen Chamber Studies Aid Minneapolis-St. Paul Works." G. J. Schroepfer and K. L. Mick, pp. 268–272.
"Sewer Rental Finances Operation at Bowling Green." A. H. Smith and A. H. Niles, pp. 275–276.
"Laboratory Control of Sewage Treatment. X. Chemical Treatment." F. W. Gilcreas, pp. 279–280.
"Status of Sewage and Industrial Wastes Disposal in the U. S. Illinois, Louisiana and Tennessee." C. W. Klassen, J. H. O'Neill, and H. D. Schmidt, pp. 281–283.
"Michigan Continues Progress on Industrial Waste Problem," p. 286.
"Valves Used at Sewage Treatment Plants" (discussion), pp. 287–288.

Public Works

March, 1937.
"Trenching for Sewer Construction," pp. 14–16.
"Large Sludge Pump for Joint Sewage Plant," p. 16.
"Equalizing flow to Treatment Plant from Intermittent Pumping." M. N. Hammon, Jr., pp. 27–28.

April, 1937.
"Elutriation Methods and Equipment." A. L. Ginter, pp. 11–14.
"An 8-community Sewage Project," p. 16.
"Sewer Construction under Difficult Conditions," p. 23.

May, 1937.
"Trenching for Sewer Construction," pp. 11–13.
"A Sewage Gas Incinerator Burns Scum and Screenings," p. 20.
"Improvements to Princeton Sewage Treatment Plant," pp. 23–24.
"Two European Sewage Treatment Processes," p. 24.
"Review of Sewerage Developments in England in 1936," p. 26.
"Some Sewer Practices, Wise and Otherwise," p. 28.
"A New Kind of Sewer Manhole," p. 30.

Water Works and Sewerage

February, 1937.
"Sewerage and Sewage Treatment in Review." C. G. Hyde, pp. 33–39.
"Dry Cleaning" Air Diffuser plates. A. M. Rawn, p. 44.
"Largest Sewage Works Association (New York) Stages Record-making Meeting," pp. 49–55.
"The Effect of Activated Carbon on Sludge Digestion." C. E. Keefer and H. Kratz, Jr., pp. 56–57.
"Sewage Treatment Designed to Handle Industry's Wastes." C. C. Hommon, pp. 64–66.
"Phoenix Sewage Plant Gets Much Needed Detritor." D. Travanini, pp. 67–68.
"A Sprinkling Filter that Would a Swimming Hole Be." L. Goodrich, pp. 69– .

March, 1937.

"Sewerage and Sewage Treatment in Review." C. G. Hyde, pp. 71–80.
"The Newer Methods of Sewage Works Financing." C. W. Klassen and W. H. Wisely, pp. 88–93.
"Some Laboratory Kinks and Time-savers." C. A. Habermehl, pp. 96–98.
"Flow Study on 'Separate' Sanitary Sewer System." V. W. Willits, p. 107.

April, 1937.

"Operating Control Tests for the Activated Sludge Process." T. R. Hazeltine, pp. 121–123.
"The Rehabilitation of a Badly Damaged Sewer." W. D. Darby, pp. 130–131.
"Sludge Disposal by Incineration." P. B. Streander, pp. 132–136.